MONTHLY 7/6

The Journal of THE ROYAL AERONAUTICAL SOCIETY

CONTENTS JUNE 1950

MODERN METHODS OF TESTING AERO-ENGINES AND POWER PLANTS *A. C. LOVESEY, O.B.E., B.Sc., F.R.Ae.S.*

PROTOTYPE TESTING OF AIRCRAFT *D. R. H. DICKINSON, A.F.R.Ae.S.*

ERNST MACH—PIONEER OF SUPERSONICS *JOSEPH BLACK, M.Sc., A.F.R.Ae.S.*

85th ANNUAL REPORT OF COUNCIL 1949-1950

REVIEWS

CORRESPONDENCE

LONDON

ROYAL AERONAUTICAL SOCIETY, 4 HAMILTON PLACE, W.1

On the Spot-
DOWTY
Service
Engineers, located at Factory and Service Aerodromes throughout the world, are always available for the installation and maintenance of the Company's products
DOWTY EQUIPMENT LIMITED · CHELTENHAM

THE ROYAL AERONAUTICAL SOCIETY

GRADUATES' AND STUDENTS' SECTION

Notice *June* 1950

Members of the Section who were unable to speak at the Discussion Evening on "The Training of an Aeronautical Engineer" on 18th April 1950 are invited to send contributions in writing to M. C. Campion, 6A Mildenhall Road, Clapton, E.5.

UNDERCARRIAGE DESIGN AND TESTING

by

G. S. CRANWELL, Grad.R.Ae.S.

The following is a summary of the lecture given on 28th March 1950:—

INTRODUCTION

The various duties of the undercarriage unit may be summarised as follows:—

1. In landing, the undercarriage must reduce the vertical velocity of the aircraft to zero by absorption and dissipation of the vertical energy of descent, ultimately in the form of heat. If incompletely dissipated the residual energy will produce a rebound.

2. The chassis must permit smooth motion while taxi-ing and manœuvring over undulating ground and surface irregularities.

3. The chassis must be so disposed as to permit the aircraft to be readily brought to a flying attitude for take-off with the minimum of ground friction so as to give the greatest possible acceleration.

LANDING CONSIDERATIONS

The exact vertical and forward velocities and the degree to which the aircraft is airborne at the instant of landing are somewhat variable, depending upon the pilot's judgment. Thus the value of the vertical velocity used in design must be chosen largely from experience.

Statistics have shown that the vertical impact velocity for conventional land-based aircraft seldom exceeds 10 ft./sec. Consequently values of 11 ft./sec. for civil aircraft and 12 ft./sec. for military aircraft have been selected as British design figures. These assume that the whole aircraft weight is airborne and has no potential energy at impact. Thus the energy to be absorbed by the chassis is kinetic and equal to $(WV^2)/2g$ where W is the aircraft landing weight and V the vertical velocity. For naval aircraft, a descent velocity of 14 ft./sec. has been chosen to cater for the more severe operating conditions. As a rule, the landing weight and descent velocity are defined in the specification.

In studying the manner in which the chassis absorbs energy it is convenient to consider, first, the case of a stiff wheel and undercarriage leg. On impact the chassis will instantaneously transmit the impact load from the ground to the aircraft structure which will deflect under this load, the area under the load/deflection graph being equal to the energy absorbed, *i.e.* the kinetic energy of descent. The deflection of the aircraft structure will be of a small order and hence the loads will be high. However, by increasing the deflection of the system, the load is decreased for the same energy absorption. If the ground reaction be R and the deflection δ the energy absorbed is $\frac{1}{2}R\delta$ assuming a perfectly elastic deflection. Since in general, the load/deflection curve of a shock absorber is not linear this result is expressed as

Energy absorbed $=\eta R\delta=(WV^2)/2g$ where $\eta=$efficiency.

The load R is commonly expressed as a multiple of the aircraft weight *i.e.* $R=\lambda W$.

Hence $\eta W\delta=(WV^2)/2g$ or $\delta=V^2/(2g\eta\lambda)$

Thus λ represents the deceleration of the aircraft in "g."

The maximum permissible value of the reaction factor, λ, should not exceed 7.0 for physiological reasons but in practice a value of 3.0 is common, 5.0 being a practical limit. A value of 2.5 is in general use for large civil aircraft. The reaction is also limited by the load carrying capacity of the tyre which is chosen to give about 95 per cent. closure under full impact load, *i.e.* the tyre must not "bottom" under impact. This enables its energy absorption qualities to be exploited to the full. Furthermore, the tyre deflection should not exceed 35 per

cent. under static load or a high rate of wear will result. It should be noted that a tyre, being elastic, does not dissipate energy and thus a chassis using only a tyre as a shock absorber would give an undesirably high rebound.

Types of shock absorber

The various types of shock absorber in general use are

i Rubber in compression
ii Spring
iii Pre-loaded spring
iv Oleo pneumatic strut
v Liquid spring.

The use of rubber gives a low efficiency, less than 50 per cent., but is convenient for light aircraft.

The plain spring yields an efficiency of 50 per cent. but by pre-loading the spring this figure may be improved to some 75 per cent. However, a long spring with a high initial stress is subject to fatigue.

The oleo pneumatic strut utilises air in compression with oil damping, the total reaction being constituted of the forces due to these, plus friction. The air compression follows a polytropic law of approximately the form $p = p_0\left(\frac{v}{v_0}\right)^{1.3}$ in landing movements returning to isothermal values under static conditions. The friction consists principally of bearing friction, due to the wheel load not being taken axially by the oleo. It is usually greatest when the aircraft lands with drift or yaw resulting in an appreciable sideload. Wheel drag during "spinning-up" of the wheel can also contribute to bearing friction. Thus it is necessary to ensure that the oleo does not seize from excessive friction which dictates the bearing overlap/overhang ratio. This should never be less than 1.0. It should be noted that the above ratio usually decides the overall length of the conventional oleo which for a value of 1.0 cannot be less than 3.5 × stroke.

The alternative to the oleo strut for many duties is the liquid spring in which compression of the oil at high pressures occurs with piston closure, damping being provided by orifices in the piston. Such a unit is small and compact, despite much thicker wall sizes resulting from the high pressure. Not only is the oil compression considerable at 50,000 p.s.i. but that of steel is detectable as approximately 0.5 per cent. Corresponding figures for oils vary considerably depending on the constituents, typical figures being 8 per cent. for glycerine and 16 per cent. for Dowty S.A. fluid.

Undercarriage Testing

Tests are generally of two types, ultimate strength testing and drop testing, of which the former corresponds to the usual airframe strength tests.

In a drop test, the chassis energy absorption is verified and adjustment made to the damping orifices where necessary. The complete chassis is supported in a skip moving between vertical guide pillars. The specified impact velocity is obtained by dropping the skip and chassis from a pre-determined height. The load on the skip must be adjusted to give the same total energy absorption as a non-airborne drop test or that specified for a fully airborne landing. Thus the weight on the skip is somewhat less than the proportion of the aircraft weight to be carried by the unit under test.

During the impact, the reaction measured by means of an accelerometer must not exceed the design figure nor must the tyre or strut bottom. Occasionally, since the effects of the aircraft structure cannot be reproduced by the skip, the whole aircraft must be drop tested to investigate structural dynamic effects. Side and drag loads are reproduced by dropping the undercarriage on to a wedge. This may be either a plain wedge lubricated with castor oil or formed of two wedges with the inclined faces placed together on rollers.

It is important that the correct natural frequency be chosen for the accelerometer. An instrument of low natural frequency, *e.g.* 20 cycles when undamped will show large oscillations of the instrument response with respect to the input pulse. The same instrument with heavy damping exhibits a large phase lag between response and input. If the natural frequency be high, *e.g.* 80 cycles and the instrument correctly damped the deviation from input is of small amplitude, but interference from such sources as engine vibrations may cause blurring of the response.

THE ROYAL AERONAUTICAL SOCIETY

4 HAMILTON PLACE, PICCADILLY, LONDON, W.1. GROSVENOR 3515-9

NOTICES JUNE 1950

SECRETARYSHIP OF THE SOCIETY

The Secretaryship of the Royal Aeronautical Society will become vacant on the approaching retirement of Captain J. Laurence Pritchard, and the Council now invite applications for the post.

The Secretary is the executive officer of the Society, responsible to the Council for implementing the policy of the Society and managing its affairs. He is head of the permanent staff and it is his responsibility to maintain close relationship with other engineering and scientific institutions and societies, official organisations and the like, and the Society's Divisions and Branches Overseas. The Secretary is also responsible for organising the Society's social functions.

Preference will be given to candidates with an aeronautical background who have had administrative experience. The salary will be in the range of £1,250 to £1,500 depending upon qualifications. The post is pensionable at 65.

Applications should be addressed to the Secretary, 4 Hamilton Place, London, W.1 before 31st July 1950.

CONTENTS OF THE JUNE JOURNAL

Modern Methods of Testing Aero-Engines and Power Plants, A. C. Lovesey, O.B.E., B.Sc., F.R.Ae.S.
Prototype Testing of Aircraft, D. R. H. Dickinson, A.F.R.Ae.S.
Ernst Mach—Pioneer of Supersonics, Joseph Black, M.Sc., A.F.R.Ae.S.
85th Annual Report of Council 1949-1950.
Reviews.
Correspondence.

THE AERONAUTICAL QUARTERLY—Volume II

Part I, Volume II, of "The Aeronautical Quarterly" is now available from the offices of the Society at 7s. 9d. each to members of the Society, post paid, or 10s. 3d. each to non-members, post paid.

The contents are:—

Two-Dimensional Theory of Stiffened Plates	Chang O'Chou
The Whirling of a Spinning Top	J. Morris
The Possibility of the Determination of Rate of Climb from Acceleration Measurements in Level Flight ...	E. C. Pike
A Note on Subsonic Aerofoil Theory	John W. Miles
Theory of an Oscillating Supersonic Aerofoil	Geoffrey L. Sewell
The Linearised Theory of Conical Fields in Supersonic Flow, with Applications to Plane Aerofoils	S. Goldstein and G. N. Ward

Volume I of "The Aeronautical Quarterly" (copies of which are still available) has been well received both in Great Britain and overseas; the response has been encouraging and reviews published both in this country and the United States have

praised and welcomed both the appearance and contents of the Society's new publication. As the circulation increases more papers will be published in each part.

The special attention of members is drawn to the fact that a strictly limited edition only of "The Aeronautical Quarterly" is printed and numbers can not be reprinted in any circumstances. An annual subscription is therefore advisable.

COUNCIL FOR 1950-51

Council for 1950-51 is as follows:—

President—Major G. P. Bulman, C.B.E., B.Sc., F.R.Ae.S.

Past Presidents—Sir John S. Buchanan, C.B.E., F.R.Ae.S.
H. Roxbee Cox, Ph.D., D.I.C., F.R.Ae.S.
Sir Frederick Handley Page, C.B.E., Hon.F.R.Ae.S.

Vice-Presidents—S. Camm, C.B.E., F.R.Ae.S.
G. R. Edwards, M.B.E., B.Sc., F.R.Ae.S.
Major F. B. Halford, C.B.E., F.R.Ae.S.

Council Members.

Lord Brabazon of Tara, M.C., Hon.F.R.Ae.S.
A. V. Cleaver, A.R.Ae.S.
G. P. Douglas, C.B.E., M.C., D.Sc., F.R.Ae.S.
A. G. Elliott, C.B.E., F.R.Ae.S.
W. S. Farren, C.B., M.B.E., M.A., F.R.S., F.R.Ae.S.
Sir A. H. Roy Fedden, M.B.E., D.Sc., F.R.Ae.S.
Sir Arthur Gouge, B.Sc., F.R.Ae.S.
Professor A. A. Hall, M.A., F.R.Ae.S.
S. Scott Hall, C.B., M.Sc., D.I.C., F.R.Ae.S.
N. J. Hancock, A.F.R.Ae.S.
J. W. F. Housego, Grad.R.Ae.S.
E. T. Jones, O.B.E., M.Eng., F.R.Ae.S.
P. G. Masefield, M.A., F.R.Ae.S.
W. G. A. Perring, C.B., F.R.Ae.S.
N. E. Rowe, C.B.E., B.Sc., D.I.C., F.R.Ae.S.
W. Tye, O.B.E., B.Sc., F.R.Ae.S.
C. F. Uwins, A.F.C., O.B.E., F.R.Ae.S.
Honorary Librarian—J. E. Hodgson, Hon.F.R.Ae.S.
Honorary Treasurer—C. F. Uwins, A.F.C., O.B.E., F.R.Ae.S.
Solicitor—L. A. Wingfield, M.C., D.F.C., A.R.Ae.S.
Secretary—Captain J. Laurence Pritchard, Hon.F.I.Ae.S., Hon.F.R.Ae.S.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Society was held at 4 Hamilton Place, W.1, on the 15th May 1950, at which the Annual Report and Balance Sheets of The Royal Aeronautical Society and Aeronautical Trusts Ltd. for 1949 were approved. The complete Report and Balance Sheets are published in the June JOURNAL. For the information of those who do not receive the JOURNAL the excess of expenditure over income for 1949 amounted to £4,560.

The following elections were announced at the Annual General Meeting:—

Honorary Fellows—

Robert Blackburn, O.B.E., A.M.Inst.C.E., M.I.Mech.E., M.I.P.E.
Sir Richard Fairey, M.B.E.
T. O. M. Sopwith, C.B.E.
Lt. Col. Mervyn O'Gorman, C.B., D.Sc., M.I.Mech.E., M.I.E.E.
Sir Francis K. McClean, A.F.C.

Fellows—

J. L. P. Brodie, M.I.A.E., M.I.Mech.E.
Air Vice-Marshal R. O. Jones, C.B., A.F.C.
E. J. Richards, M.A.
P. L. Teed.
F. W. Whitehead.
C. T. Wilkins.

Honorary Companions—

Marshal of the R.A.F. The Lord Douglas of Kirtleside, G.C.B., K.C.B., M.C., D.F.C.
Air Marshal Sir Alec Coryton, K.B.E., C.B., M.V.O., D.F.C.
Major Sir Hew Kilner, M.C.
C. G. Grey.

THE SOCIETY'S BADGES

The Society's Badges, the one which was in use until the granting of the Royal Charter, and the present one, have both been registered under the Trade Marks Act 1938 at the Patent Office, Trade Marks Registry.

The registration of these Badges prevents their designs or any obvious imitation of them being used by unauthorised persons.

The Society is indebted to Mr. F. J. Cleveland, an Associate Fellow, who first drew the attention of the Society to the importance of having the Badges registered and who generously gave his time to prepare and carry through the necessary applications to the Patent Office.

SOCIETY OF BRITISH AIRCRAFT CONSTRUCTORS EDUCATIONAL GRANTS

The attention of members is drawn to the Society of British Aircraft Constructors Educational Grants administered by the Society.

The Grants are designed for the assistance of young men who are unable, for financial reasons, to obtain training in aeronautical engineering. All holders of S.B.A.C. grants are expected to qualify for a technical grade in the Royal Aeronautical Society.

Applicants should be between the ages of 16 and 18 on the 1st September in the year of the award. The closing date for applications for this year is 30th June 1950. Application forms may be obtained from the Secretary.

MEMBER'S NEW APPOINTMENT

A. D. Baxter, Esq., M.Eng., M.I.Mech.E., A.F.R.Ae.S., has been appointed to the Chair of Aircraft Propulsion at the College of Aeronautics.

FOURTH WORLD POWER CONFERENCE

The Fourth World Power Conference will be held in London from 10th to 15th July 1950. Full particulars may be obtained from the offices of the Conference at 414 Cecil Chambers, 76 Strand, London, W.C.2. The papers for the Conference comprise some 150 from 27 National Committees, including several on Aircraft Gas Turbines from Great Britain, France and the U.S.A. Mr. F. M. Owner, C.B.E., M.Sc., F.R.Ae.S. and Dr. S. G. Hooker, O.B.E., D.Phil., B.Sc., F.R.Ae.S., Chief Engineer and Assistant Chief Engineer, Bristol Aeroplane Co. Ltd., are giving a paper on, "Powerplant Requirements for Future Aircraft."

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Donald Charles Allen (from Associate), Nora Helen Atkin (from Graduate), Neil William Vincent Barford, Gilbert Edward Barrett, Cecil Baxter, Gordon Day Bennett, Allan Bond, Eric Lewis Bond, Arthur Ronald Butler (from Associate), Jasper Stephen Butcher (from Graduate), Alfred Neil Byron, Patrick James Campbell (from Student), Thomas Martin Chalmers (from Graduate), John Chambers, Francis Victor Davies (from Graduate), Ivan Francis Robert Dickinson, Frank Augustus Drayton, Peter William Dryland (from Graduate), John Leon Edwards, Reginald George Evans (from Graduate), Frank Fallon, Donald Osborne Finlay, John Foley (from Graduate), Lawrence Harry Gould (from Graduate), Peter Grootenhuis; Terence Michael Hainsselin (from Associate), Derek James Hardy (from Graduate), Kenneth Lewis Hodkinson (from Graduate), Maurice Holt, Reginald Eric Hooson (from Student), Kay Hunter, Charles Alan Judson, Norman Frederick Lamb (from Associate), Gerard Niels Louw, Lyndon George McFarlane, Francis Maguiness, William Stanley Donald Marshall (from Graduate), James Allan Mollison (from Associate), Ronald Richard William Moss (from Graduate), William George Moth (from Graduate), Hubert Leslie Peddle (from Associate), George William Perrett, George Harry Hugh Powell, John Henry Powle (ex Associate Fellow), George Ritson Raisbeck, Stanley Edward Richardson (from Graduate), Walter Ralph Roberts, Harry Edgar William Robinson (from Associate), Harry Desmond Rylands, Christopher Scruton, Frederick Charles Slaughter (from Associate), Ernest Edward Smith (from Graduate), Leonard Stanley Snell, John James Spiliman (from Graduate), Antony David Stannard, John Anthony Staunton (from Graduate), Derrick Edward Joseph Tipping (from Graduate), Barry Trodd, Joan Trouncer, Norman Turner, Harold Alexander Vlies, David James Noel Wakeling, William Joseph Walker (from Graduate), George Victor Watson, Victor Willis (from Graduate), Philip John Wingham (from Student), James Wood, Charles George Woolven (from Graduate).

Associates

Arthur Ernest Ronald Broomfield, Percy Brown, George Alex Henry Eckles, James Peter Hamilton, Michael Alrick Josselyn Morton Hayward (from Graduate), Garfield Nathan Tarbet Hemmings (from Student), Stanislaw Jordon, Frank Kirk, Ian McLaren, Louis Wilfred Morton, Harold James Mossman, William Arthur Pendlebury, Frank Edward Pickles, Jean Gaston Pradal, Herbert John Rix, Reginald Louis Secker, Douglas Ramiro Walls (from Student).

Graduates

John Barker, Cyril Frank Blanks, Brian Edward Boyce (from Student), Claude Walter Brenner, Arthur John Cable (from Student), Ralph Cartwright, John Cyril Chaplin (from Student), Walter Edwin Coe, Maurice Jacob Cohen, William Stevenson Cunningham (from Student), Frederick Eric Deudney (from Student), James Philip Graham, Lewis Henry Wilson Harris (from Student), Dennis Alec Head, Gordon Sinclair Henderson, Raymond Derek Hillary, John Dennis Hodge (from Student), Peter Lionel Hughes (from Student), Roy Vernon Hurrell, Leon Bridge Jakens, Royle Bernard Denis Jansen (from Student), Johannes Lie (from Student), Donald Thomas Lincoln, Alastair Munro Mackie (from Student), John Dennis Micklem (from Student), Charles Alan Mitton, Eric Norman-Wilson (from Student), Charles Roy Pratt-Barlow (from Student), Donald Reeves, John Morton Spong (from Student), Robert Graham Taylor (from Student), John Derek Tearle (from Student), Lionel Mervyn Treleman, Jerzy Maciej Tusiewicz, Waldemar Warhaftig, Eric Enos Watts, John Bernard Wellingham, David Douglas Williams, Archibald William Alfred Prott Wilson (from Companion) Malcolm Clow Wilson, Neville Henry Wood (from Student).

Students

Richard John Adams, Philip Charles Aldridge, Allan Blair Bailey, John Charles Arthur Baldock, John Michael Beaumont, John Andrew Dennis Bradshaw, Philip Arthur Brown, Trevor Percival Brown, David Pierce Comley, Robin Ellis Cooper, Frederick Creedy, Philip Morgan Davey, Ronald John Frost, Dennis Gerald Cave Goodhead, Brian John Griffin, Gerald Kenneth Hunt, Jean Marie Antoine Joseph Jehin, Bhawani Shanker Kaushik, John Edmund Lidiard, John A. Locke, Donald Rex Manning, John Alfred Bowman May, Thomas William Nicholls, Donald Pierrepont, Derek Jess Wilton Richards, John Francis Richards, Alan George Robertson, Leonard James Rogers, Dennis William Taylor, Keith Harold William Tomlin, John Arthur Tucker, Terence David Ward, Jeremy George Waycott.

Companions

Essayed Selim Elmolla.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).

Grade of membership.

New address (in block letters).

Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

LAPEL BADGES

Lapel badges are still available to members at 3s. 6d. each, including postage. These badges are gilt enamel with a screw back and are $\frac{3}{4}$ inch in diameter. Remittances should be sent, with applications, to the Secretary at the Offices of the Society.

JOURNAL BINDING

The prices of binding of Journals is as follows:—

1949 Volume (including packing and postage), 15s. 6d.

Previous Volumes (including packing and postage), 17s. 0d.

Journals should be sent direct to the Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the offices of the Society.

Cases only for unbound 1949 Volumes are available, price 6s. 6d. each. Requests for cases, with remittances, should be sent to the Secretary at the offices of the Society.

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks the return of back numbers of the JOURNAL from: H. Bradley, Esq., *Associate*, J. Wilde, Esq., and The National Physical Laboratory.

ADDITIONS TO THE LIBRARY

The following have been added to the Library (titles of pamphlets are printed in italics and books marked * or ** may not be taken out on loan):—

Aircraft Industries Association	The Aircraft Yearbook 1949. Lincoln Press Inc. 1949.
American Mathematical Society	First Symposium in Applied Mathematics, Vol. I. American Mathematical Society. 1949.

Anon.	The R.C.A.F. Overseas. The First Four Years. Oxford University Press, Toronto. 1944.
Bryant, L. A. and Dickinson, T. A.	Jigs and Fixtures for Mass Production. Pitman, New York. 1947.
Clarke, A. C.	Interplanetary Flight. Temple Press. 1950.
Gunn, D. L. and others	Aircraft Spraying Against the Desert Locust in Kenya 1945. Anti-Locust Research Centre. 1946.
Kermode, A. C.	Mechanics of Flight, Vol. I, 6th Edition. Pitman. 1950.
Knight, C. and Durham, R. C.	Hitch Your Wagon—Bernt Balchen. Bell Publishing Corporation, U.S. 1950.
Low, B. B.	Strength of Materials. Longmans Green & Co. 1949.
Orman, L. M.	Electronic Navigation. Pan-American Navigation Service & Weems System of Navigation. 1950.
Schmid, E. and Boas, W.	Plasticity of Crystals. F. A. Hughes & Co. 1950.
Shaw, M. C. and Macks, E. F.	Analysis and Lubrication of Bearings. McGraw-Hill. 1949.
Teed, P. L.	Properties of Metallic Materials at Low Temperatures. Chapman & Hall. 1950.
Zahm, A. F.	Aeronautical Papers. Two volumes. University of Notre Dame. 1950.

N.A.C.A. Technical Notes

2014—*Static longitudinal stability and control of a convertible airplane as affected by articulated- and rigid-propeller operation. R. H. Lange and H. C. McLermore.*

2027.—*Friction and wear of hot-pressed bearing materials containing Molybdenum Disulfide. R. L. Johnson, M. A. Swikert and E. E. Bisson.*

2034—*First-order theory for unsteady motion on thin wings at supersonic speeds. B. Moskowitz and W. E. Moeckel.*

2035—*A method of determining the effect of airplane stability on the gust load factor. N. Mazelsky and F. W. Diederich.*

2037—*Resistance of six cast high-temperature alloys to cracking caused by thermal shock. M. J. Wightman, R. W. Hall and C. Yaker.*

2039—*Investigation of fretting corrosion by microscopic observation. D. Godfrey.*

2041—*An experimental investigation of the NACA 631-012 airfoil section with leading-edge and midchord suction slots. G. B. McCullough and D. E. Gault.*

2043—*Experimental analysis of a pressure-sensitive system for sensing gas temperature. R. S. Cesaro, R. J. Koenig and G. J. Pack.*

N.A.C.A. Reports

903—*Theoretical and experimental data for a number of NACA 6A-series airfoil sections. L. K. Loftin, Jr.*

906—*Determination of stresses in gas-turbine disks subjected to plastic flow and creep. M. B. Millenson and S. S. Manson.*

914—*Effect of centrifugal force on the elastic curve of a vibrating cantilever beam. S. H. Simpkinson, L. J. Eatherton and M. B. Millenson.*

915—*Extension of useful operating range of axial-flow compressors by use of adjustable stator blades. J. T. Sinnette and W. J. Voss.*

917—*The effects of aerodynamic heating and heat transfer on the surface temperature of a body of revolution in steady supersonic flight. R. Scherrer.*
918—*Theoretical motions of hydrofoil systems. F. H. Imlay.*
929—*Dislocation theory of the fatigue of metals. E. S. Machlin.*

A.R.C. Reports and Memoranda

2281—*Normalised orthogonal deflexion functions for beams. W. J. Duncan.*
2286—*The new whirling arm at the National Physical Laboratory. A. S. Halliday, P. H. Allwork and H. N. Caborn.*
2287—*Further wind tunnel tests on a 30 per cent. symmetrical suction aerofoil with a movable flap. H. Gregory and W. S. Walker.*
2292—*A new family of low drag wings with improved C_L-ranges. B. Thwaites.*
2293—*The use of equivalent slopes in vortex lattice theory. V. M. Falkner.*
2295—*Low-speed model tests on a "U" wing. J. Trouncer and G. F. Moss.*
2308—*An analysis of the lift slope of aerofoils of small aspect ratio, including fins, with design charts for aerofoils and control surfaces. D. J. Lyons and P. L. Bisgood.*
2310—*The longitudinal stability of a twin-engined monoplane with airscrews running. L. W. Bryant and G. A. McMillan.*
2311—*An analysis of some abnormal developments of the thrown line type in paratroop parachute equipment. S. B. Jackson.*
2314—*Experiments on a 20 per cent. control with tab, fitted to NACA 0015 aerofoil, with especial reference to effect of its section on hinge moment and lift. A. S. Batson, J. H. Warsap and T. W. Brown.*
2315—*Note on the effect of deformation of a control flap on lift and hinge moment. A. S. Batson and J. H. Warsap.*
2317—*Flight measurements of the directional stability and trim on the Mustang III with various modifications to improve the directional stability. H. V. Becker and D. J. Lyons.*
2321—*Investigation of the flow past finite wedges of 20 degrees and 40 degrees apex angle at subsonic and supersonic speeds, using a Mach-Zehnder interferometer. D. C. Pack.*
2330—*Critical conditions for compressible flow. W. G. Bickley.*
2335—*The effects of various factors on parachute characteristics. T. F. Jones and E. I. Auterson.*
2343—*Photographs of sprays from pressure jets. A Simons and G. R. Goffe.*
2357—*24-ft. tunnel tests on a Rotol wooden Spitfire propeller. Test results, and data for single radius calculations. A. B. Haines and P. B. Chater.*
2360—*A comparison of the measured and calculated twist along a propeller blade. A. B. Haines.*
2377—*The structural and aerodynamic effects of wing thickness and fuselage size variation. A. G. Pugsley, W. Tye and H. J. Allwright.*
2381—*Notes on the dog fight. S. B. Gates.*
2382—*Note on the relation between turning and straight performance. S. B. Gates.*
2395—*A note on side and floor aperture jumping. G. W. Cartling.*
2428—*Model tests on a high-lift aircraft Folland E28/40. Part I—Tests on aileron. Part II—Tests on tailplane. Part III—Resultant force on wing slot. A. S. Halliday, D. K. Cox and W. C. Skelton.*

Aeronautical Research Laboratories, Australia

SM.144—*The influence of aeroplane characteristics on the response to gusts of various forms. F. H. Hooke.*
A.66 & SM.142—*Gust loads on two-dimensional aerofoils in supersonic flow. J. R. M. Radok.*
Structures and Materials Note No. 180—*Statistical properties of fatigue data on 24S-T aluminium alloys. A. K. Head.*

Royal Institute of Technology, Stockholm

Aero TN.9—*Efficiency of aeroplane propellers at high speed flight. O. A. M. Holme.*

Aero TN.12—*The effect of compressibility on the flow around slender bodies of revolution. L. Oswatitsch.*

Flygtekniska Forsokstalten, Sweden

31—*Comparative wind tunnel tests of a swept-back and a straight wing having equal aspect ratios. O. Holme.*

32—*A numerical solution of the problem of the lifting surface with continuous distribution of vorticity. O. Holme.*

Publications Scientifiques et Techniques du Ministere de l'Air

N.T.32—*Un nouveau manographe photo-electrique. B. Barret.*

J. LAURENCE PRITCHARD,
Secretary.

Lewes Press (Wightman & Co. Ltd.), Friars Walk, Lewes, Sussex.

LINKING AUSTRALIA
PACIFIC ISLANDS
AND THE EAST
WITH THE U.K.

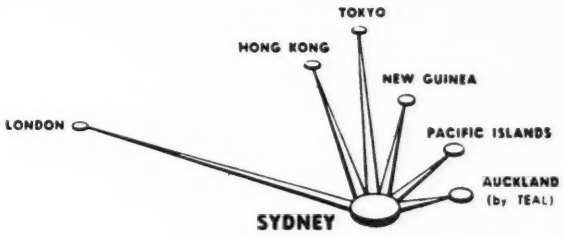
Q·E·A

AUSTRALIA'S INTERNATIONAL AIRLINE

Services: LONDON—SYDNEY via Italy, Egypt, Pakistan, India, Ceylon, Singapore and Java by Kangaroo Service, in parallel with B.O.A.C. SYDNEY—HONG KONG via Labuan. SYDNEY—TOKYO via Manila. SYDNEY—NEW GUINEA via Northern Queensland airports. SYDNEY—PACIFIC ISLANDS including Lord Howe, Norfolk Island, Noumea and Suva. SYDNEY—AUCKLAND (by T.E.A.L.) links with Kangaroo Service. *Full details from all travel agents.*

QANTAS EMPIRE AIRWAYS

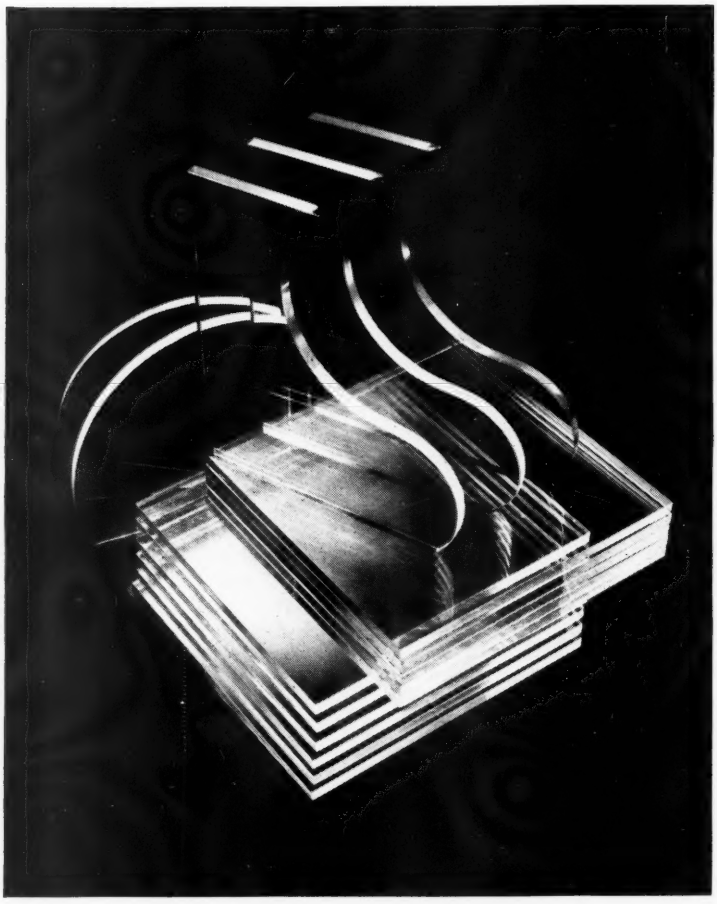
Australia's International Airline—Operating regular services on over 30,000 miles of unduplicated air routes



IN ASSOCIATION WITH BRITISH OVERSEAS AIRWAYS CORPORATION

'PERSPEX'

ACRYLIC SHEET



Supplied in thicknesses and sizes suitable for many purposes.

the versatile material of

INDUSTRY

'Perspex' is the registered trade mark of the acrylic sheet manufactured by I.C.I.

ICI

IMPERIAL CHEMICAL INDUSTRIES LIMITED

LONDON, S.W.1

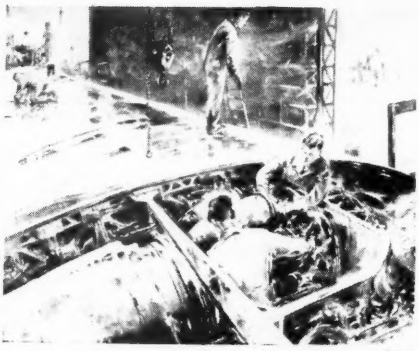
P.407z

898A

40 years progress . . .

On February 19th, 1910, The Bristol Aeroplane Company Limited was founded. The "Box-Kite"—first production aircraft—began a record of nearly 200 "Bristol" types. Fighter, Bulldog, Blenheim, Beaufort, Beaufighter and Brigand are a few aircraft names which, with Jupiter, Pegasus, Hercules and Centaurus engines, have made "Bristol" a name world-renowned in aviation. The Bristol Aeroplane Company Limited points with pride to a forty-year record of steady progress achieved largely by the encouragement of individual thought and enterprise among its workers.

THE *Bristol* AEROPLANE COMPANY LIMITED · ENGLAND



A34

The increasing speed and weight of modern aircraft demands the best possible materials. More and more designers specify

DURALUMIN

REGD TRADE MARK

The strong light aluminium alloy marketed solely by BOOTH BIRMINGHAM

JAMES BOOTH AND COMPANY LIMITED

ARGYLE STREET WORKS · BIRMINGHAM · 7

THE AERONAUTICAL QUARTERLY

Volume II MAY 1950 Part I

CONTENTS

Two-Dimensional Theory of Stiffened Plates	*Chang O'Chou*
The Whirling of a Spinning Top	*J. Morris*
The Possibility of the Determination of Rate of Climb from Acceleration Measurements in Level Flight	*E. C. Pike*
A Note on Subsonic Aerofoil Theory	*J. W. Miles*
Theory of an Oscillating Supersonic Aerofoil	*Geoffrey L. Sewell*
The Linearised Theory of Conical Fields in Supersonic Flow, with Applications to Plane Aerofoils	*S. Goldstein and G. N. Ward*

LONDON
ROYAL AERONAUTICAL SOCIETY
4 HAMILTON PLACE W1

10/-

. . . two contributions to 'pay-load' and safety

'FLEXELITE'

The new LIGHT WEIGHT FLEXIBLE FUEL TANK of SYNTHETIC RUBBER and NYLON FABRIC.

'MAREX'

LIGHT ALLOY HEAT EXCHANGERS COOLERS, INTERCOOLERS RADIATORS, etc., etc.

Fullest co-operation and advice from our Development Departments

MARSTON EXCELSIOR LTD

(A subsidiary company of Imperial Chemical Industries Ltd.)

WOLVERHAMPTON (TEL. FORDHOUSES 2181) AND LEEDS

MAR.518

D. NAPIER & SON LIMITED · LONDON W. 3

B.O.A.C. TAKES GOOD CARE OF YOU

ACROSS THE *Atlantic*

—and to all 6 continents

Ask your local B.O.A.C. Appointed Agent about *Stratocruiser* Speedbird services across the Atlantic. Ask him about the speed, comfort and double-decked spaciousness of these large, fast, luxurious airliners.

Ask him too about B.O.A.C.'s other Speedbird services to fifty-one countries on all six continents. He makes no charge for expert advice, detailed information or bookings.

GET THERE SOONER! STAY THERE LONGER!

FLY BRITISH BY B·O·A·C

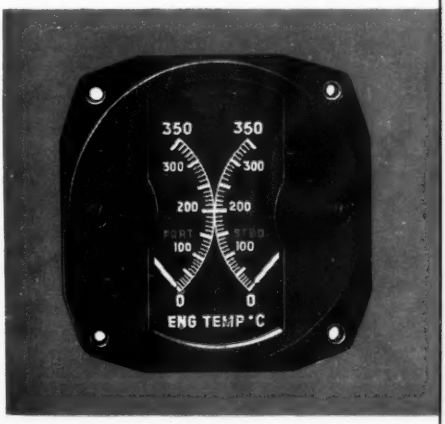
BRITISH OVERSEAS AIRWAYS CORPORATION

Airways Terminal, Buckingham Palace Road, London, S.W. 1. Telephone: VICtoria 2323

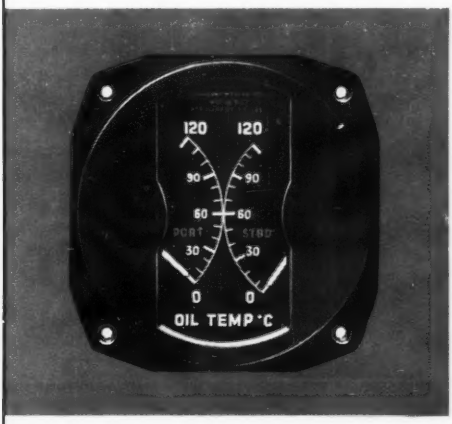
WESTON
AIRCRAFT INSTRUMENTS

No. 1. Temperature Measuring

The comprehensive range of Weston temperature measuring instruments covers the requirements of existing production aircraft, as well as types now under development. In addition to thermometry for the indication of cylinder, air, oil and radiator temperatures, Weston equipment for aircraft includes instruments for supply, navigational aid instruments, selector switches, etc.



Model S. 128. Dual Engine Temperature Indicator, comprising two Millivoltmeters of 100° scale housed in large-size S.A.E. case. For use in conjunction with copper/constantan, iron/constantan, or chrome/alumel thermocouples.



Model S. 127. Dual Ratiometer Indicator, comprising two 100° ratiometer movements housed in large-size S.A.E. case. For use in conjunction with thermometer bulbs, electrical oil pressure transmitters, electrical position indicators or any combination of two of these to indicate a variety of temperatures, pressures or positions

SANGAMO WESTON LIMITED · Enfield · Middlesex

Tel.: Enfield 3434 (6 lines) and 1242 (4 lines). Grams: Sanwest, Enfield

Scottish Factory: Port Glasgow · Renfrewshire · Scotland

Area Depots: 201 St. Vincent St., Glasgow, Tel.: Central 6208. Milburn House, Newcastle-on-Tyne, Tel.: Newcastle 26867. 22 Booth St., Manchester, Tel.: Central 7904. 33 Princess St., Wolverhampton. Tel.: Wolverhampton 21912.

The first and only electrical Turn and Slip Indicator
approved for service with the ROYAL AIR FORCE
PULLIN
1000 HOURS NORMAL PERIOD
BETWEEN INSPECTIONS
10 SLIP 10
TURN

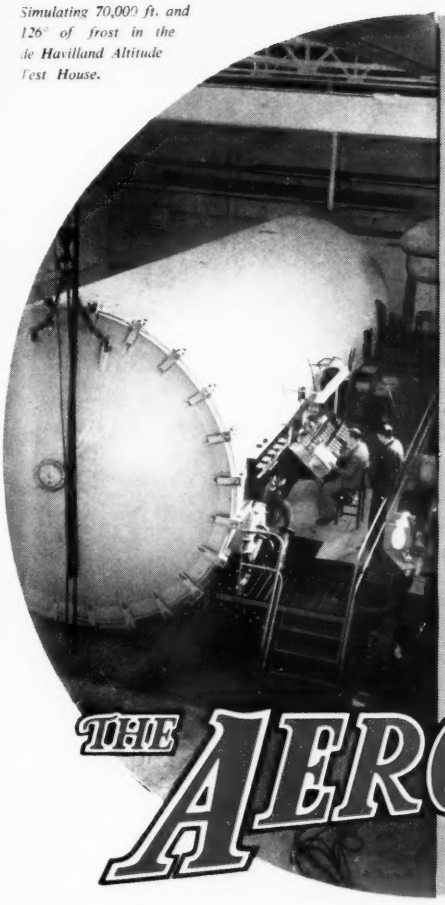
Write direct for fully illustrated leaflet to the sole manufacturers—

R. B. PULLIN & CO. LTD., PHŒNIX WORKS, GREAT WEST ROAD, BRENTFORD, MIDDLESEX

Telephone EALing 0011/3 and 3661/3. Telegrams: PULLINCO, Wesphone, London

16197

Simulating 70,000 ft. and 126° of frost in the de Havilland Altitude Test House.



Imparting Essential Data . . .

THE AEROPLANE

Just as the results achieved in *collecting* data depend on the methods used in research, so the success of 'The Aeroplane' in *presenting* information is due to forethought and experienced planning.

Accounts are lucidly written and brought to life by well-chosen illustrations; enough specific data are included to support the main themes, but never enough to overshadow them; and invariably the particular aspects of research development or operation are shown against the general progress of aviation as a whole.

Friday, One Shilling *3.1.0 a year, post free*

TEMPLE PRESS LIMITED

BOWLING GREEN LANE, LONDON, E.C.1. TERMINUS 3636

THE MOTOR · THE COMMERCIAL MOTOR · CYCLING
PLASTICS · THE OVERSEAS ENGINEER · THE AEROPLANE
THE MOTOR SHIP · THE LIGHT CAR

THE MOTOR BOAT AND YACHTING · LIGHT METALS
BRITISH FARM MECHANIZATION · MOTOR CYCLING
THE OIL ENGINE AND GAS TURBINE

THE WORLD'S FIRST PROPELLER TURBINE AIRLINER

AT.86

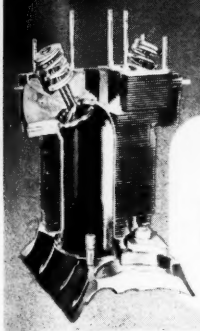
The Viscount Flies into a Great Future

THE VISCOUNT 700 proves at every stage to be worthy of its distinguished forbears. Its brilliant performance, safety and comfort were fully proved right from the first take-off. Next it acquired the Normal Certificate of Airworthiness to I.C.A.O. standards. Now, the Viscount goes into operation for the world's airlines.

VICKERS-ARMSTRONGS LTD · AIRCRAFT SECTION VICKERS HOUSE · BROADWAY · LONDON · S

WELLWORTHY

Quality Products



AL-FIN
INTEGRAL BI-METALLIC BONDING OF IRON AND ALUMINIUM

PISTONS
OF EVERY TYPE FOR EVERY APPLICATION

PISTON RINGS
FOR AERO ENGINES AND SEALING RINGS FOR GAS TURBINES

We shall be glad to hear if you are interested in any problem concerning Pistons or Piston Rings. AL-FIN Bonding, the newest development combining weight saving with maximum heat transfer is exclusive to Wellworthy in this country. Full details will be sent on request.

WELLWORTHY PISTON RINGS LTD
RADIAL WORKS · LYMINGTON · HANTS

CHAPMAN & HALL

have pleasure in announcing a new series of

MONOGRAPHS ON METALLIC MATERIALS

Published under the authority of **THE ROYAL AERONAUTICAL SOCIETY**

First titles

The Properties of Metallic Materials at Low Temperatures

by P. LITHERLAND TEED A.F.R.AE.S.

Demy 8*vo* 232 *pages* 8 *Figs.* 21*s. net*
(Published 28th April)

The Structure and Mechanical Properties of Metals

by BRUCE CHALMERS D.SC., F.INST.P., ETC.

Demy 8*vo* 160 *pages* 89 *Figs.*
About 18*s. net*
(In the Press)

Other titles include:

Fatigue, Stress Corrosion and Corrosion Fatigue of Aeronautical Metals and Alloys at Normal Temperatures

by C. W. GEORGE

Creep of Aircraft Materials

by L. ROTHERHAM

37 ESSEX STREET, LONDON, W.C.2

SILICONES

are already important to the

AIRCRAFT INDUSTRY

Silicones have heat-resisting and water-repellent properties that have important applications in the Aircraft Industry. They can be used in the form of Liquids, Resins, Greases and Rubbers (Silastic).

SILICONE FLUIDS are subject to low viscosity changes over wide temperature ranges. They are suitable for damping, hydraulic and instrument fluids.

SILICONE RESINS AND VARNISHES are heat-stable and water-repellent. They provide electrical insulation that is serviceable at temperatures at least 50°C. above Class B limits.

SILICONE GREASES AND COMPOUNDS are lubricants suitable for bearings and valves operating at high and low temperatures. DC4, the Ignition Sealing Compound, has many applications.

SILASTIC is a rubber-like material that remains flexible over the temperature range of —50° to 260°C. It is suitable for special purpose gaskets, and for insulating electrical wires and cables.

Albright & Wilson are developing the use of silicones in this country. They will be glad to send fuller particulars of these products.

SILICONES

ALBRIGHT & WILSON LTD

Distributors of Dow Corning Silicones

49 PARK LANE · LONDON · W.1 · TEL: GRO. 1311

WWW 109

Electric Equipment for Aircraft

With unrivalled manufacturing resources, backed by continual research and development and fifty-three years' experience, BTH enjoys an enviable reputation for the quality of its products. Reliability is of prime importance on land, but is vital in the air, hence the success of BTH aircraft magnetos, and electrical equipment including:

Motor-generating sets with electronic regulators · A.C. and D.C. Motors · Actuators · Gas-operated turbo-starters · Generators · Mazda lamps, etc.

BRITISH THOMSON-HOUSTON

THE BRITISH THOMSON-HOUSTON CO., LTD., COVENTRY, ENGLAND

A4028

DATA SHEETS

ON

AERODYNAMICS

STRESSED SKIN STRUCTURES

PERFORMANCE

And Now

FUELS & LUBRICANTS

READY IN JUNE 1950

(prepared in conjunction with the Institute of Petroleum)

Write for full particulars to:

The Royal Aeronautical Society

4 HAMILTON PLACE, LONDON, W.1.

Have you a MATERIAL Problem?

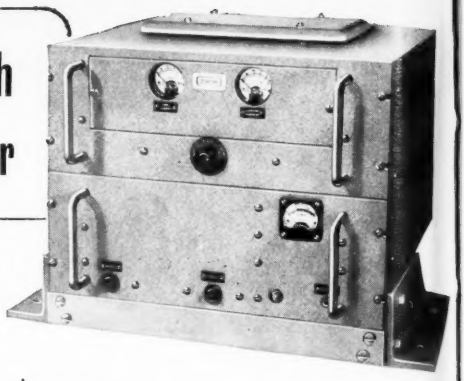
Much of our work consists in supplying answers to problems affecting the choice of a metal or alloy for a specific job. We have the research staff, equipment and the metallurgical experience, and we welcome the opportunity of helping you to choose the right material.

THE MOND NICKEL COMPANY LTD

Sunderland House, Curzon Street, London, W1

51/CM/31

Control is simpler with this V.H.F. Transmitter



V.H.F. Fixed Station Transmitter P.T. 10

- Specifically designed for local airport control.
- 12 watts carrier. 100% modulation. Controls are covered to prevent accidental movement.
- Built-in adjustable compressor circuit prevents over-modulation and distortion.
- Operates in the 116-132 Mc/s band, frequency being crystal controlled and easy to change. Other ranges between 70-184 Mc/s can be made available as required.
- Neat two-panel construction is available for desk mounting as illustrated, or for rack mounting with other equipment.
- Fully tropicalised in accordance with R.S. 1000.
- An illustrated brochure (Publication No. 398) is available. Write also for brochures describing other Plessey GROUND and AIR communications equipment.

CES

Plessey

COMMUNICATIONS ENGINEERING DIVISION · THE PLESSEY COMPANY LIMITED · ILFORD · ESSEX

AERONAUTICAL REPRINTS

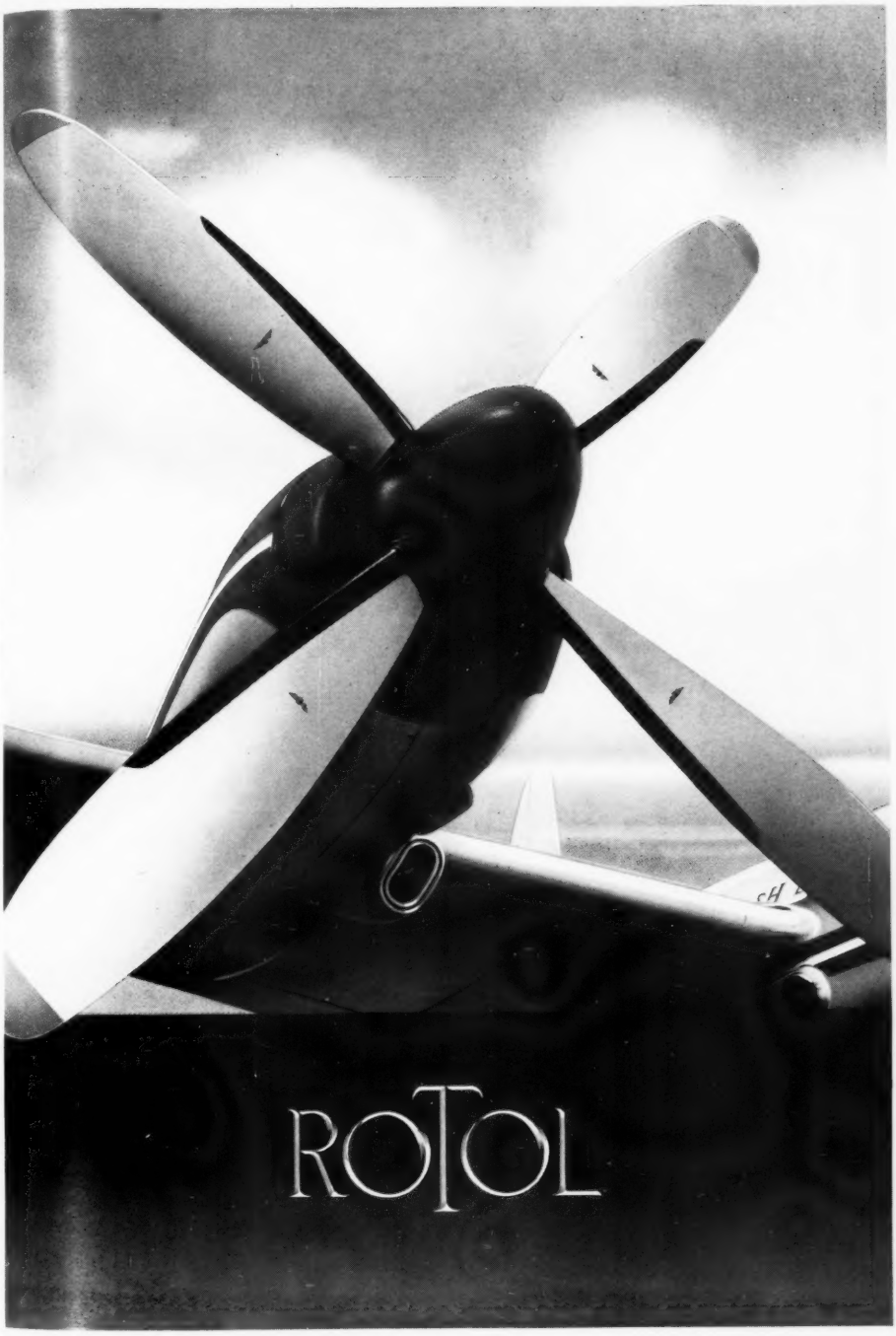
The following are titles of some of the more recent REPRINTS of important papers published in the JOURNAL :—

100		**The Importance of Power Unit Development**, by Air Commodore F. R. Banks, O.B.E., F.R.Ae.S.	7/6
101		**Aviation's Place in Civilisation**, by T. P. Wright, D.Sc., Hon.F.R.Ae.S., F.I.Ae.S.	7/6
102		**Control Surface Design in Theory and Practice**, by M. B. Morgan, M.A., F.R.Ae.S., and H. H. B. M. Thomas, B.Sc., A.F.R.Ae.S.	7/6
103		**Australia in Empire Air Transport**, by W. Hudson Fysh, D.F.C.	7/6
104		**Recent Aerodynamic Developments**, by Ernest F. Relf, C.B.E., A.R.C.S., F.R.S., F.R.Ae.S.	7/6
106	108 113	**The General Theory of Cylindrical and Conical Tubes Under Torsion and Bending Loads**, by J. Hadji-Argyris, Dipl.Eng., and P. C. Dunne, B.Sc. **Parts I-IV** (106) **Part V** (108) **Part VI** (113)	10/- 10/- 10/-
107		**The Development of All-Wing Aircraft**, by John K. Northrop	7/6
109		**The Problems of High Temperature Alloys for Gas Turbines**, by Sir William T. Griffiths, D.Sc., F.R.I.C., F.Inst.P., F.I.M.	7/6
110		**Aircraft and the Airlines—A Canadian View**, by James T. Bain	7/6
111		**Size in Transport**, by Sir Arthur Couge, B.Sc., F.R.Ae.S.	7/6
112		**Some Economic Factors in Civil Aviation**, by P. G. Masefield, M.A., F.R.Ae.S., M.I.Ae.S.	10/-
114		**The Aeronautical Research Scene—Goals, Methods and Accomplishments**, Hugh L. Dryden, M.A., Ph.D., F.R.Ae.S., Hon.F.I.Ae.S.	10/-
115		**Inter-City Transport Development on the Commonwealth Routes**, by E. H. Atkin, B.Sc., F.R.Ae.S.	10/-

A full List may be had on application to—

The Secretary, ROYAL AERONAUTICAL SOCIETY

4 HAMILTON PLACE, LONDON, W1. Grosvenor 3515-19


ROTOL

Behind this undercarriage . .

Behind this undercarriage and behind the hydraulic and pneumatic equipment of this company there is a background of design experience, research and testing which contributes towards supplying the ideal component for the job.

ELECTRO-HYDRAULICS LIMITED

WARRINGTON

Telephone WARRINGTON 2244

Main Undercarriage for Hermes IV and V

DESIGNERS & MANUFACTURERS OF HYDRAULIC, PNEUMATIC AND ELECTRIC EQUIPMENT

J.N.931

pul
ori
pap
CO

Sci
obt
lett

MA

only
for
pap

begi

refe
end
conc

ILLU

that
All

flat

whit

MAT

writt
belo

shou
one

over

than

that

Engli
be gi

PAPERS FOR THE JOURNAL

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the JOURNAL. Both members and non-members are invited to contribute original papers on their own special subjects. The following notes on the preparation of papers for the JOURNAL are given to assist contributors:—

COPYRIGHT

The copyright of every paper printed in the JOURNAL shall be the property of Aerial Science Limited. If the author makes use of copyright material in his paper or information obtained by reason of his employment or otherwise, he must state clearly in his covering letter, or in the paper, that consent has been given for the use of such material.

MANUSCRIPTS

Papers must be in English, in the third person, and typed on one side of the paper only, with double spacing and wide margins. When submitted they must be in their *final form for publication.* Only typographical errors may be corrected in proofs. Titles of papers should be brief.

Where practicable, a summary of not more than 250 words should be given at the beginning of the paper, giving its scope and conclusions.

All references should be numbered in the text where they occur, and the complete list of references given at the end of the manuscript. These references will be published at the end of the text. Footnotes should be numbered consecutively. Tables should be kept as concise as possible.

ILLUSTRATIONS

Illustrations must be drawn so that they will reduce to column or two-column width, that is to $2\frac{5}{8}$ or $5\frac{1}{2}$ inches. Full page illustrations must reduce to $5\frac{1}{2}$ inches by 8 inches. All drawings must be in black ink on white paper or tracing cloth.

Lettering and figures on drawings must be in pencil only. Drawings should be posted flat or rolled.

Photographs should not be less than half plate in size and must be clear black and white glossy prints.

Every drawing and photograph should have on the back its figure number and title.

MATHEMATICS

Only very simple symbols and formulæ should be typewritten. All others should be written carefully by hand in ink. Ample space for marking should be allowed above and below all equations. Greek letters should be designated by name in the margin.

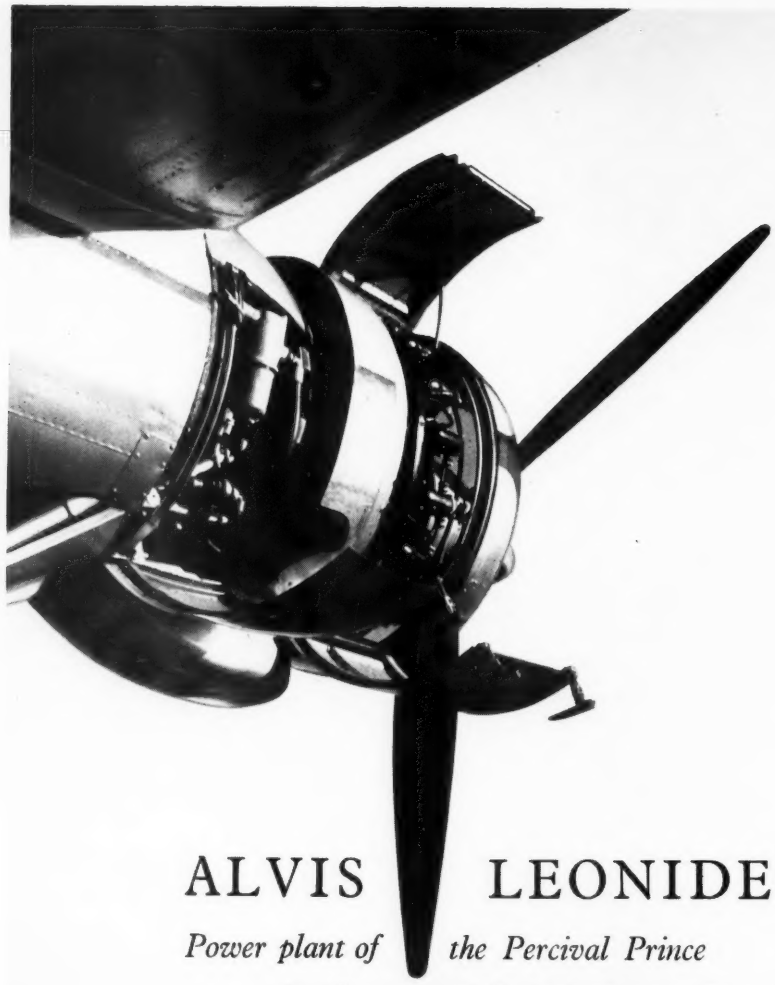
The difference between capital and lower-case letters should be clearly shown; care should be taken to avoid confusion between zero (0) and the letter o, between the numeral one (1) and the letter l, between alpha and a, kappa and k, mu and u, nu and v, eta and n.

All subscripts and exponents should be clearly marked, and dots, bars, and so on, over letters should be avoided as far as possible.

Square roots of complicated expressions should be written with the exponent $\frac{1}{2}$ rather than with the sign $\surd$.

Complicated exponents and subscripts should be avoided. Any complicated expression that recurs frequently should be represented by a special symbol.

Unless an abbreviation is one recognised as standard practice, both in this and other English-speaking countries, for example, b.h.p. for brake horse power, the meaning should be given in full on its first use.



ALVIS LEONIDES

Power plant of the Percival Prince

Providing power to enable the aircraft to meet the requirements of I.C.A.O., the Alvis Leonides also meets the Operator's demands for speedy maintenance inspections. Large hinged cowling panels provide notably easy access

ALVIS LIMITED · COVENTRY · ENGLAND
Telephone: Coventry 5501

OFFICIALS OF THE BRANCHES OF THE SOCIETY IN THE UNITED KINGDOM

BELFAST
President: Professor G. T. R. HILL, M.C., M.Sc., M.I.Mech.E., F.R.Ae.S.
Chairman: Rear Admiral M. S. SLATTERY, C.B., F.R.Ae.S., R.N. (Retd.).
Secretary: J. A. KIRK, Esq., A.F.R.Ae.S., Short Brothers & Harland Ltd., Queen's Island, Belfast, N.I.

BIRMINGHAM
President: S. C. REDSHAW, Esq., F.R.Ae.S.
Secretary: C. P. HOMES, Esq., A.R.Ae.S., 81 Peplins Way, Kings Norton, Birmingham, 30.

BRISTOL
President: Air Chief Marshal Sir ARTHUR BARRATT, C.M.G., M.C.
Chairman: F. G. EVANS, Esq., B.Sc., F.R.Ae.S.
Secretary: B. P. LAIGHT, Esq., M.Sc., A.M.I.Mech.E., A.F.R.Ae.S., Aircraft Division, Bristol Aeroplane Co. Ltd., Filton, Bristol.

BROUGH
President: R. BLACKBURN, Esq., O.B.E., A.M.I.C.E., M.I.Mech.E., F.R.Ae.S.
Chairman: G. E. PETTY, Esq., M.I.Mech.E., F.R.Ae.S.
Secretary: F. A. WILKINSON, Esq., A.F.R.Ae.S., Design Office, Blackburn & General Aircraft Ltd., Brough, E. Yorks.

COVENTRY
President: H. M. WOODHAMS, Esq., C.B.E., [F.R.Ae.S.
Chairman: W. J. PETERS, Esq.
Secretary: C. T. SCULTHORPE, Esq., A.F.R.Ae.S., Design Dept., Sir W. G. Armstrong Whitworth Aircraft Ltd., Baginton, Coventry.

DERBY
President: E. W. HIVES, Esq., C.H., M.B.E., F.R.Ae.S.
Chairman: A. G. ELLIOTT, Esq., C.B.E., F.R.Ae.S.
Secretary: J. L. BATCHELOR, Esq., A.R.Ae.S., 154 Littleover Lane, Derby.

GLASGOW
Chairman: T. B. LYON, Esq., A.F.R.Ae.S.
Secretary: G. YOUNG, Esq., B.Sc., M.I.Ae.S., c/o Design Office, Scottish Aviation Ltd., Prestwick Airport, Ayrshire. [A.F.R.Ae.S.

GLOUCESTER AND CHELTENHAM
President: A. L. MILNER, Esq., Wh.Sc., A.M.I.C.E., F.R.Ae.S.
Chairman: R. W. WALKER, Esq., F.R.Ae.S.
Secretary: J. F. CUSS, Esq., A.M.I.Mech.E., c/o Gloster Aircraft Co. Ltd., Witcombe, Gloucester. [A.F.R.Ae.S.

HATFIELD
President: Sir GEOFFREY DE HAVILLAND, C.B.E., A.F.C., R.D.I., Hon.F.I.Ae.S., F.R.Ae.S.
Chairman: J. E. WALKER, Esq., A.F.R.Ae.S.
Secretary: E. J. MANN, Esq., A.M.I.Mech.E., de Havilland Aircraft Co. Ltd., Hatfield, Herts. [A.R.Ae.S.

ISLE OF WIGHT
President: Sir ARTHUR GOUGE, B.Sc., M.I.Mech.E., F.R.Ae.S.
Chairman: H. KNOWLER, Esq., A.M.I.C.E., F.R.Ae.S.
Secretary: P. H. CURNOW, Esq., Grad.R.Ae.S., Design Office, Saunders-Roe Ltd., Osborne, I.o.W.

LEICESTER
Chairman: W/Cdr. H. E. FALKNER, A.F.R.Ae.S.
Secretary: F. WATKIN, Esq., B.Sc., A.F.R.Ae.S., Auster Aircraft Ltd., Rearsby, Leicester.

LUTON
Chairman: S. A. CLARKE, Esq., A.F.R.Ae.S.
Secretary: P. A. DRILLIEN, Esq., A.R.Ae.S., c/o D. Napier & Son Ltd., Luton, Beds.

MANCHESTER
President: Sir ROY H. DOBSON, C.B.E., J.P., F.R.Ae.S.
Chairman: C. E. FIELDING, Esq., O.B.E., M.I.P.E., A.F.R.Ae.S.
Secretary: J. A. E. WATERFALL, Esq., 56 Manor Avenue, Ashton-on-Mersey, Cheshire.

PORTSMOUTH
President: A. TOWNSLEY, Esq.
Chairman: E. C. GREEN, Esq.
Secretary: E. M. BELLAMY, Esq., c/o Airspeed Ltd., The Airport, Portsmouth, Hants.

PRESTON
President: Sir GEORGE NELSON, M.I.Mech.E., M.I.E.E.
Chairman: W. E. W. PETTER, Esq., F.R.Ae.S.
Secretary: D. B. SMITH, Esq., O.B.E., M.A., A.M.I.Mech.E., A.F.R.Ae.S., English Electric Co. Ltd., Aircraft Division, Warton Aerodrome, Nr. Preston, Lancs.

READING
President: Sir FREDERICK HANDLEY PAGE, C.B.E., Hon.F.R.Ae.S.
Chairman: E. W. GRAY, Esq., B.Sc., A.M.I.Mech.E., A.F.R.Ae.S.
Secretary: E. L. PEARSON, Esq., A.R.Ae.S., c/o Handley Page (Reading) Ltd., The Aerodrome, Woodley, Reading, Berks.

SOUTHAMPTON
Chairman: A. N. CLIFTON, Esq., F.R.Ae.S.
Secretary: T. TANNER, Esq., A.F.R.Ae.S., University College, Southampton, Hants.

WEYBRIDGE
President: G. R. EDWARDS, Esq., M.B.E., B.Sc., F.R.Ae.S.
Chairman: H. H. GARDNER, Esq., B.Sc., F.R.Ae.S.
Secretary: J. H. SINCLAIR, Esq., A.R.Ae.S., Vickers-Armstrongs Ltd., Weybridge, Surrey.

YEOVIL
Secretary: L. A. LANSDOWN, Esq., A.F.R.Ae.S., Westland Aircraft Ltd., Yeovil, Somerset.

FIRTH BROWN

1837–1950

EXPERIENCE & DEVELOPMENT IN HIGHEST QUALITY STEELS OF ALL GRADES

As manufacturers of Alloy Steels for High Duty, Firth Brown's contribution to industry is world wide, whether it be steels for engineering, shipbuilding, automobile, aircraft, road and rail transport or for the most minute mechanisms of the precision engineering industries. Firth Brown Steels were used for parts of the "Brabazon," built by the Bristol Aeroplane Company Limited.

LIST OF PRODUCTS

Forgings—Light and Heavy for special and general engineering.

Forged Steel Drums and Pressure Vessels.

Hardened Steel Rolls.

Carbon and Alloy Steel Bars and Billets.

Tyres and Laminated Springs.

High Speed and Tool and Die Steels.

Steel Castings.

Write for the Firth Brown Buyers' Guide for further particulars.

THOS. FIRTH & JOHN BROWN LTD, SHEFFIELD

THE ROYAL AERONAUTICAL SOCIETY

COUNCIL 1950 – 1951

PRESIDENT

MAJOR G. P. BULMAN, C.B.E., B.Sc., F.R.Ae.S.

PAST PRESIDENTS

SIR JOHN S. BUCHANAN, C.B.E., F.R.Ae.S., A.M.I.Mech.E.
H. ROXBEE COX, Esq., Ph.D., B.Sc., D.I.C., F.R.Ae.S., F.I.Ae.S.
SIR FREDERICK HANDLEY PAGE, C.B.E., Hon.F.R.Ae.S.

VICE-PRESIDENTS

S. CAMM, Esq., C.B.E., F.R.Ae.S.
G. R. EDWARDS, Esq., M.B.E., B.Sc., F.R.Ae.S., A.M.I.Struct.E.
MAJOR F. B. HALFORD, C.B.E., F.R.Ae.S.

COUNCIL MEMBERS

LORD BRABAZON OF TARA, M.C., Hon.F.R.Ae.S.
A. V. CLEAVER, Esq., A.R.Ae.S.
DR. G. P. DOUGLAS, O.B.E., M.C., D.Sc., F.R.Ae.S.
A. G. ELLIOTT, Esq., C.B.E., F.R.Ae.S., M.S.A.E.
W. S. FARREN, Esq., C.B., M.B.E., M.A., F.R.S., F.R.Ae.S., M.I.Mech.E.
SIR A. H. ROY FEDDEN, M.B.E., D.Sc., F.R.Ae.S., M.I.Mech.E., F.R.S.A., M.S.A.E.
SIR ARTHUR GOUGE, B.Sc., F.R.Ae.S., M.I.Mech.E.
PROFESSOR A. A. HALL, M.A., F.R.Ae.S.
S. SCOTT HALL, Esq., C.B., A.C.G.I., M.Sc., D.I.C., F.R.Ae.S.
J. W. F. HOUSEGO, Esq., Grad.R.Ae.S.
N. J. HANCOCK, Esq., A.F.R.Ae.S.
E. T. JONES, Esq., O.B.E., M.Eng., F.R.Ae.S.
P. G. MASEFIELD, Esq., M.A., F.R.Ae.S.
W. G. A. PERRING, Esq., C.B., F.R.Ae.S.
N. E. ROWE, Esq., C.B.E., B.Sc., D.I.C., F.R.Ae.S.
W. TYE, Esq., O.B.E., B.Sc., F.R.Ae.S.
CAPTAIN C. F. UWINS, A.F.C., O.B.E., F.R.Ae.S.

Honorary Librarian: J. E. HODGSON, Esq., Hon.F.R.Ae.S., A.F.I.Ae.S.

Honorary Treasurer: CAPTAIN C. F. UWINS, A.F.C., O.B.E., F.R.Ae.S.

Solicitor: L. A. WINGFIELD, Esq., M.C., D.F.C., A.R.Ae.S.

Secretary: CAPTAIN J. LAURENCE PRITCHARD, Hon.F.R.Ae.S., Hon. F.I.Ae.S.

THE SOCIETY'S AWARDS

The Society offers a number of valuable awards, most of them annually. Full particulars of the conditions attaching to these awards may be obtained on application to the Secretary.

Society's Gold Medal

The highest honour which the Society can confer for work of an outstanding nature in aeronautics.

Society's Silver Medal

Awarded for work of an outstanding nature in aeronautics.

Society's Bronze Medal

Awarded for work leading to advance in aeronautics.

British Gold Medal for Practical Achievement in Aeronautics

Awarded for outstanding practical achievement leading to advancement in aeronautics.

British Silver Medal for Practical Achievement in Aeronautics

Awarded for practical achievement leading to advancement in aeronautics.

Wakefield Gold Medal

Awarded annually, at the discretion of the Council, to the designer or inventor of any apparatus tending towards safety in flying.

The George Taylor (of Australia) Gold Medal

Awarded annually, at the discretion of the Council, for the most valuable paper read during the previous session.

Simms Gold Medal

Awarded annually, at the discretion of the Council, for the most valuable contribution read before, or received by, the Society on any subject allied to aeronautics, *e.g.* structures, meteorology, metrology, etc.

Herbert Akroyd Stuart Memorial Prize

Awarded at the discretion of the Council for the most valuable contribution read before, or received by, the Society on applied thermodynamics.

Edward Busk Memorial Prize

Awarded annually, at the discretion of the Council, for the most valuable contribution read before, or received by, the Society on applied aerodynamics.

Orville Wright Prize

Offered annually for the best contribution on some subject of a technical nature in connection with aeronautics, which is received by the Society and published in *The Aeronautical Quarterly*.

Pilcher Memorial Prize

Awarded annually, at the discretion of the Council, for the most valuable paper read by a Graduate or Student during the previous year at any meeting of the Society or its Branches.

Usborne Prize

Awarded annually, at the discretion of the Council, for the best contribution to the Society's publications written by a Graduate or Student on some subject of a technical nature in connection with aeronautics.

R. P. Alston Memorial Prize

Awarded for practical achievement associated with the flight testing of aircraft.

Major Baden-Powell Memorial Prize

Awarded to the best entrant in the Associate Fellowship Examination.

Wilbur Wright Memorial Premium

The Wilbur Wright Memorial Lecture is held annually, a premium of £75 being awarded to the lecturer, if British, or £125 if he is an American, invited by the Council to deliver the lecture. The lecture is usually given alternately by an American and an Englishman, and is the most important aeronautical lecture of the year.

British Commonwealth and Empire Lecture

The British Commonwealth and Empire Lecture is delivered annually by a lecturer chosen in alternate years from the British Dominions and Colonies and Great Britain.

The British Commonwealth and Empire Lecture has a premium of £50 and in the case of lecturers from the Dominions and Colonies an allowance is paid towards the lecturer's expenses.

Branch Prize

The Council offer an annual prize of twenty guineas for the best paper read before the Branches during the previous lecture session. The prize is open to any member of the Society or of any Branch.

MODERN METHODS OF TESTING AERO-ENGINES AND POWER PLANTS

by

A. C. LOVESEY, O.B.E., B.Sc., F.R.Ae.S.

The 797th Lecture to be read before the Royal Aeronautical Society was given on 30th March 1950, at the Institution of Civil Engineers, Great George Street, London, S.W.1. The President of the Society, Sir John S. Buchanan, C.B.E , F.R.Ae.S., introduced the lecturer, Mr. A. C. Lovesey, O.B.E., B.Sc., F.R.Ae.S., Chief Development Engineer, Rolls-Royce Ltd., who had been mainly responsible for the development of the Rolls-Royce Merlin engine and later of Rolls-Royce Gas Turbines and was now in charge of the Avon development.

1. INTRODUCTION

IN the early days of aero-engines the test equipment was limited to little more than a brake or dynamometer, a fuel flow meter and a few thermometers, and the development of these engines in the direction of better performance and reliability, to a large extent, was an art, built up of experience aided by instinct, of deducing the happenings inside an engine from the few meagre measurements obtainable.

Nevertheless, the aero-engine made healthy progress, became more complicated in the process, and introduced many more problems. The test equipment, of necessity, improved, and such measuring devices as the "Farnboro' High Speed Indicator," the Stroboscope, strain gauges and so on, became available.

A more direct approach to the measurement of conditions within the engine therefore made possible a speedier attack on the various problems.

The engine, however, remained very much of an indivisable unit and the only real attempt, at this period, to dissect the engine into components was the general use of single cylinder test stands. This technique has the advantage of facilitating the development of such units as con rods, big ends, pistons, valves and so on, but with certain limitations. Induction conditions were seldom representative of the full-scale engine with its attendant effect on performance.

The mal-distribution of the constituents of anti-detonents and its effect on valves, spark plugs and piston rings was seldom reproducible on single cylinder units.

The limitations are sometimes even greater with liquid-cooled engines, where such features as cylinder block distortions were not always faithfully reproduced in the single cylinder.

The advent of the supercharged engine gave a unit which was amenable to practically complete development on an independent test rig, similarly fuel injection systems. It is considered that much of the speed of development and success was due to these items being tested individually and removed from the obscuring influences of a full-scale engine.

The gas turbine aero-engine, as opposed to the piston engine, is readily dissectable into all its main components and much of the rapid development can be attributed to this factor.

The turbo-jet, after the early struggles of Whittle, came into the picture as a delightfully simple engine. It had its problems, but to those who graduated through the piston engine era, those problems, although large, seemed fewer.

In striving for improved performance the simplicity is rapidly being designed out of the engine and this calls for better and more specialised test equipment. This paper therefore deals exclusively with the gas turbine engine.

It is not possible, in this paper, to cover the range of modern equipment and methods available, therefore the subject has been limited to a few of the more interesting examples of methods which are in use to-day.

2. AIMS

The progress of the aviation engine in performance, in reliability and the conception and design of new projects, depends, in no small measure, upon the data obtained from some form of testing. This may come from the wind tunnel, the metallurgical laboratories, cascade rigs or high altitude chambers; it may be classified either under research or development, but it is the result of some form of test.

Facilities for this work are increasing in the shape of high speed and supersonic wind tunnels, high altitude test chambers, high power compressor and turbine rigs and so on, but it is necessary, constantly, to remember that these items are additional money spenders and absorbers of man-hours. A close watch has to be kept that the right type of test is put into this equipment and the right form of data extracted from it.

While the primary object of the use of this equipment is to improve the efficiency of the project under development it is no less important that the approach to this objective shall be conducted in the most efficient manner. This should be manifest in achieving the desired results in the shortest space of time, *i.e.* a reduction in the amount of testing hours.

Testing falls, roughly, into three categories:

(1) Component testing, which is done on rigs under simulated engine operating conditions. This form of testing is, mainly, for performance or functional investigation and occupies relatively short periods. A good example of this is the compressor, where, divorced from obscuring influences and limitations of a complete engine, the characteristics can be examined and adjusted with greater facility.

A certain amount of component endurance testing is common with smaller units, such as fuel pumps.

(2) Full-scale engine testing for performance and functional investigation. This may be either on the test bench, in an altitude test plant, or in flight.

(3) Full-scale engine endurance testing on both test bench and in flight. This frequently takes the form of 25-hour tests or 150-hour tests with the object of successfully completing the official 150-hour type test.

The time from the start of design of a new engine until the start of production is usually anything from three to four and a half years, and the engine bench testing may be between 3,000 and 5,000 hours with even more time devoted to rig testing of the main components. In addition, there may be another 1,000 hours to 1,500 hours flight testing.

Apart from the supply of engines, the biggest item of development in both time and money is endurance testing. For example, a 7,000 lb. thrust engine, when run on the standard Ministry of Supply 150-hour test will use between 80,000 and 100,000 gallons of fuel, whereas a piston engine in the 2,000 h.p. class will use about 22,000 gallons of fuel. These two examples are not comparable but show the order of increase in expenditure with which we are faced.

The average cost of testing components on the rig, *i.e.* compressor, turbine and combustion, is approximately one half of the cost of full-scale engine testing. The aim should be to include as much of the development work as possible in the first two classes of testing.

The better equipment now available and the ingenious use of better instrumentation to give us a fuller knowledge of the conditions prevailing within an engine, should contribute to an economy in the third form of testing, *i.e.* endurance. What is probably more important is that this should tend to speed up development.

Usually when a new type engine reaches the running stage the features of its specification which depart most from previous experience will have received sufficient rig development to ensure reasonable operation of the engine.

Although desirable, it is seldom possible to have rig-tested all the major components in advance of the main engine. Component testing and engine testing therefore, will be running in parallel with a new engine, but there is always the temptation to embark too early on endurance running.

A thorough calibration and investigation of the conditions within an engine at an early stage will justify and repay the apparent delay.

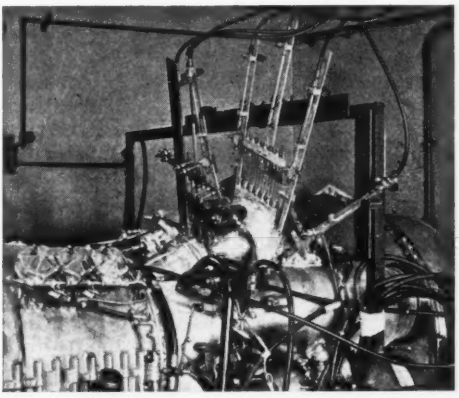
For example, a knowledge of the air flow conditions from the compressor will enable the combustion rigs to be lined up more realistically to represent engine conditions and permit an early start on any corrective measures necessary.

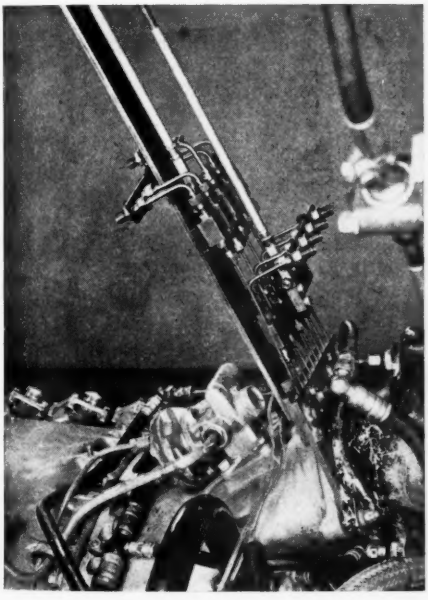
Similarly, it is desirable to make early investigation of the vibration characteristics of compressor and turbine blades.

The following sections deal with a few typical examples of specialised tests and instrumentation which are employed in obtaining a direct picture of the conditions prevailing within the engine and components.

3. METHODS OF APPROACH

The design of the testing programme for an engine and its components is no less important than the design of the engine itself,





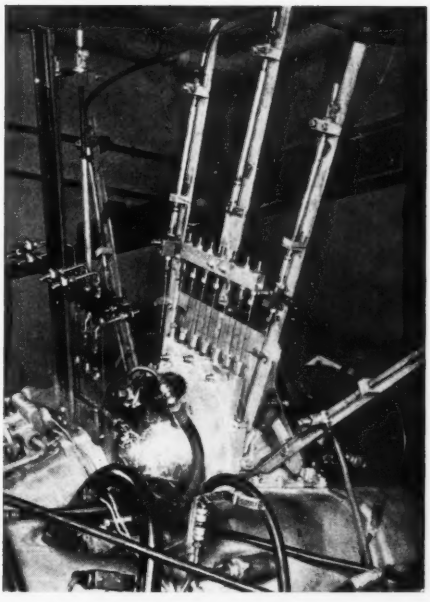


Fig. 1.
Compressor outlet traverse apparatus.

and time devoted to careful thought in this direction is well repaid. The design of special equipment or instrumentation should run in parallel with the main design so that when the engine or component is built the special test apparatus is available for the first run. Examples of this are such items as pressure and temperature tapping, devices for measuring movements or loads, all within the internals of the engine.

The programme for the testing of the major components needs careful correlation, for example, the compressor, turbine and combustion systems are very dependent upon one another. Constant cross-checks must be made between the rig and engine so that the rig shall simulate as closely as possible the operation of the engine under bench and flight conditions.

The test programme must possess certain flexibility and be reviewed almost daily in relation to the results obtained. It is sometimes obvious early on in the test that the approach is not fruitful and this may call for modification to the programme to avoid unnecessary running.

4. COMBUSTION SYSTEM

The combustion system affords several examples of specialised testing technique and will be dealt with under the headings of: "Air flow," "Combustion," and "Temperature distribution."

4.1. Air flow

Usually a new design of combustion chamber starts life on a rig where air at the required pressure, temperature and quantity, together with the requisite quantities of fuel, are supplied to the chamber under simulated operating conditions of the engine.

Development then proceeds until a satisfactory state of combustion efficiency, temperature distribution, stability range and so on, is reached, but not infrequently it is found that a combustion chamber which gave excellent results on the rig, leaves a lot to be desired on the engine.

When this happens it is nearly always due to the difference in air flow conditions on the engine compared with on the test rig. The combustion job should really start with an examination of the air flow from the compressor outlet to make sure that this is in a satisfactory condition to be accepted by the combustion chamber.

The simple apparatus used for this purpose is shown in Fig. 1. It consists of a number of pitot tubes which can traverse fully the outlet duct and the combustion chamber annulus and is simply operated from the test cabin. Details of this apparatus are shown in Fig. 2.

By this means a complete picture of the velocities at the head of the flame tube and in the air annulus can be obtained. An example

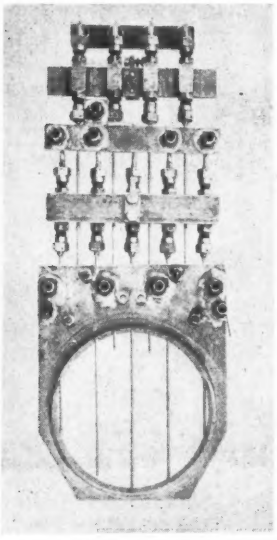
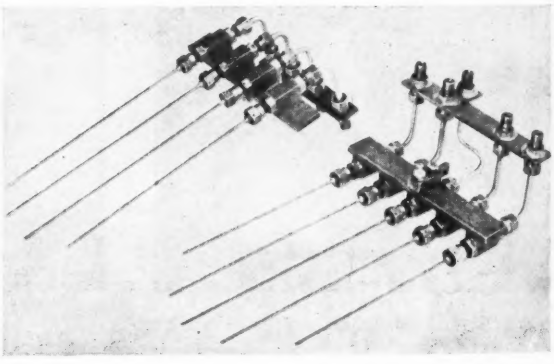


Fig. 2.
Compressor outlet measuring apparatus.



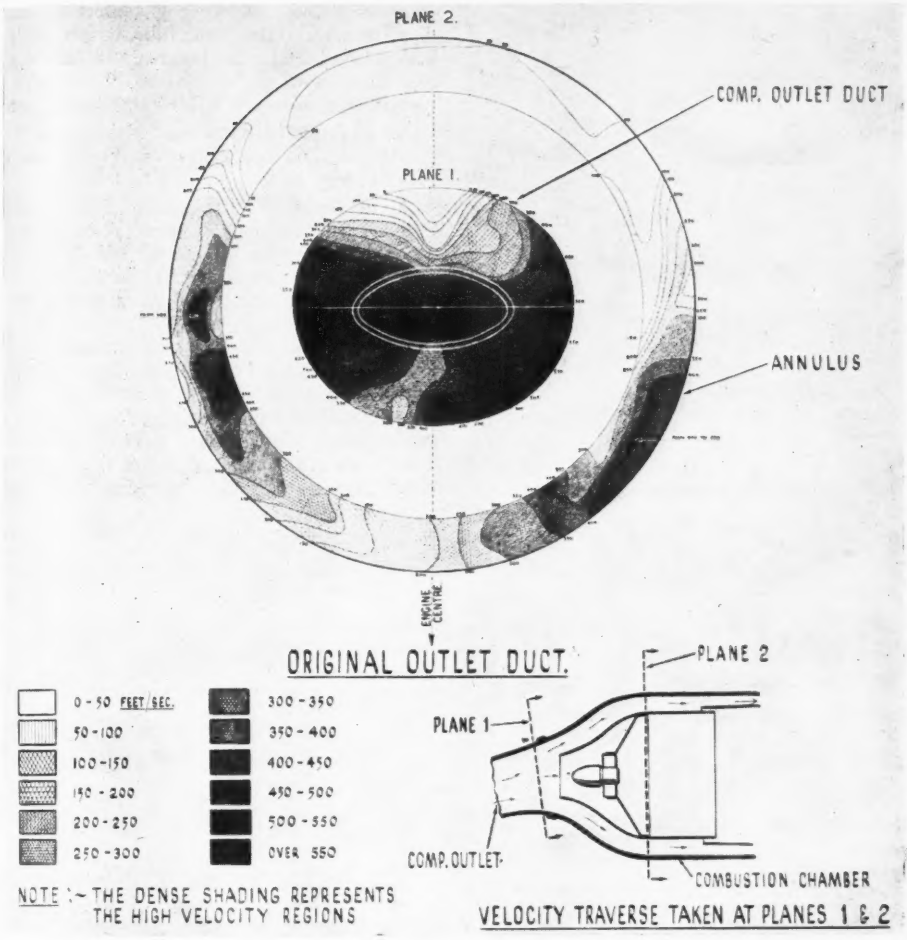


Fig. 3.

Diagram showing velocity distribution in compressor outlet duct and annulus formed between flame tube and air casing.

of this is shown in Fig. 3, in which the dark shaded areas represent regions of high velocity.

In the example shown it will be seen that a very low velocity region exists at part of the compressor outlet, with high velocity areas at the side. The low velocity region further deteriorates during expansion up to the area of the annulus round the flame tube, and through an arc of over 90° the velocity has fallen to, in some cases, below 50 feet per second, while peaks of high velocity reach values of approximately 500 feet per second.

Another method of presenting the results is by means of a celluloid model in which the height of the strips represent the velocity. This method tends to give a clearer picture of what is happening. An example is shown in Fig. 4.

It is not necessary to do prolonged engine running in order to find out if flame tubes would suffer from distortion and cracking under these conditions. Furthermore, the high velocities result in pressure losses higher

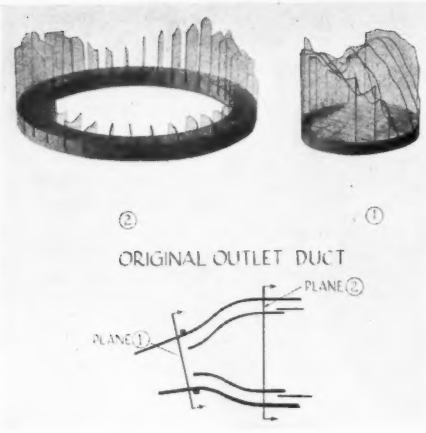


Fig. 4.
Velocity distribution models.

than need be. Another ill effect is bad distribution into the flame tube, which results in local hot patches and non-centralisation of the flame with the attendant ill effects on turbine blades which will be discussed later.

An example of flame tubes run under the conditions shown in the previous diagrams is given in Fig. 5.

A knowledge of these conditions is half the battle in overcoming the trouble and careful modification to the inside of the discharge ducts and re-arrangement of the compressor outlet guide vanes result in the velocity profile shown by the model in Fig. 6.

As will be seen in this case the velocity in the annulus round the flame tube became much more uniform and avoided the local over-heating troubles which were evident in the earlier design. The improved air flow conditions at the snout, or entry of the flame tube, had a marked improvement on the

DISTORTED REGION COINCIDING WITH LOW VELOCITY AREA IN ANNULUS.
DISTORTED REGION COINCIDING WITH LOW VELOCITY AREA IN ANNULUS.

Fig. 5.
Effect of prolonged running on flame tubes with velocity distribution shown on original duct.

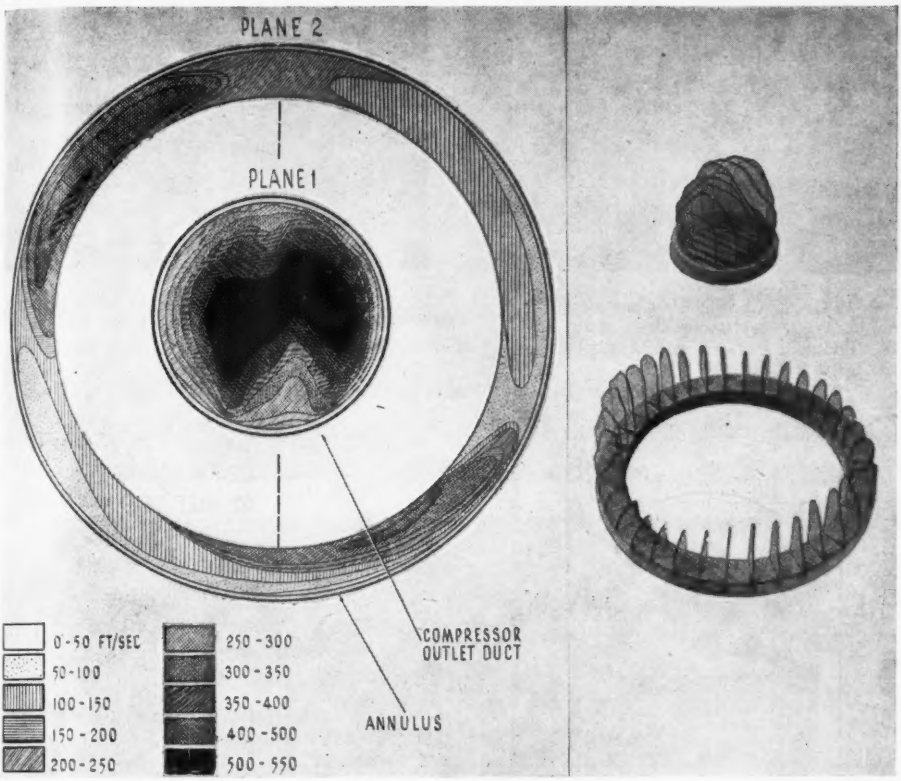


Fig. 6.

Resulting improvement in air flow obtained by modifications to compressor discharge duct.

smoothness of combustion and a reduction in flame length.

An extension of this method is also used on the rig for determining the air flow conditions within the flame tube, but these tests are run under cold conditions. These tests show clearly that the aerodynamics of the combustion system should be developed to a satisfactory state before any actual burning tests are made.

4.2. Combustion

To-day there are few bad combustion chambers inasmuch as the combustion efficiency is little below the 100 per cent. mark. Other conditions, however, have to be considered, such as the ability to operate over a wide range of air fuel ratios, in other words, to possess the maximum stability at high altitudes and, at the same time, to give a temperature traverse acceptable to the nozzle guide vanes and turbine blades.

The fuel burner is one of the major factors controlling stability at high altitudes and a high degree of atomisation should be aimed at over a wide flow range.

Figure 7 shows a burner under reduced flow conditions at 40,000 feet and it is for investigations of this sort that high speed photography is a considerable aid. The photographs were taken with a "Mullard flash tube" which gives a flash of one million candle power for a millionth of a second.

It can be seen from these pictures that the spray is very coarse and, as can be imagined, the combustion with this spray becomes very uncertain.

As the result of a thorough photographic investigation of the flow from the burner over the whole range, a form of two-stage burner

Original burner showing coarse characteristics of spray.

R. R. Duple burner developed to give good atomisation at low fuel flows.

Photographs taken with Mullard flash tube. Both burners are flowing the same quantity of fuel.

Fig. 7.
Spray characteristics from burners at idling conditions 40,000 ft.

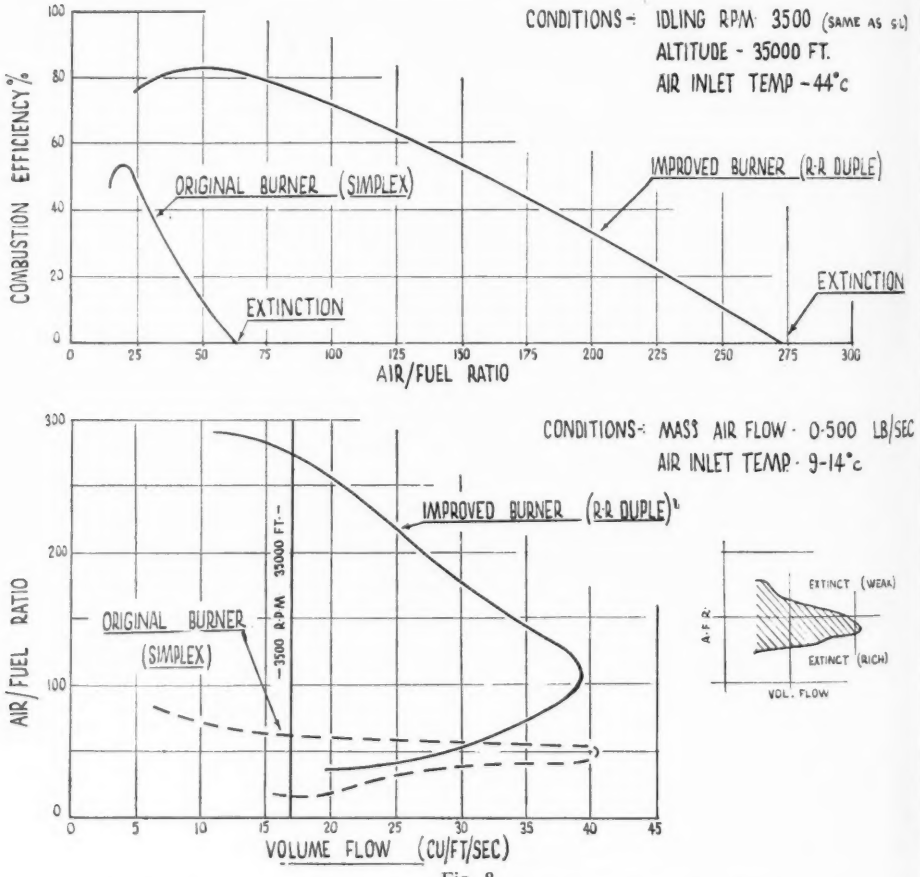


Fig. 8.
The top curves show improvement of atomisation on combustion efficiency.
The lower curves show improvement in stability range by better atomisation.

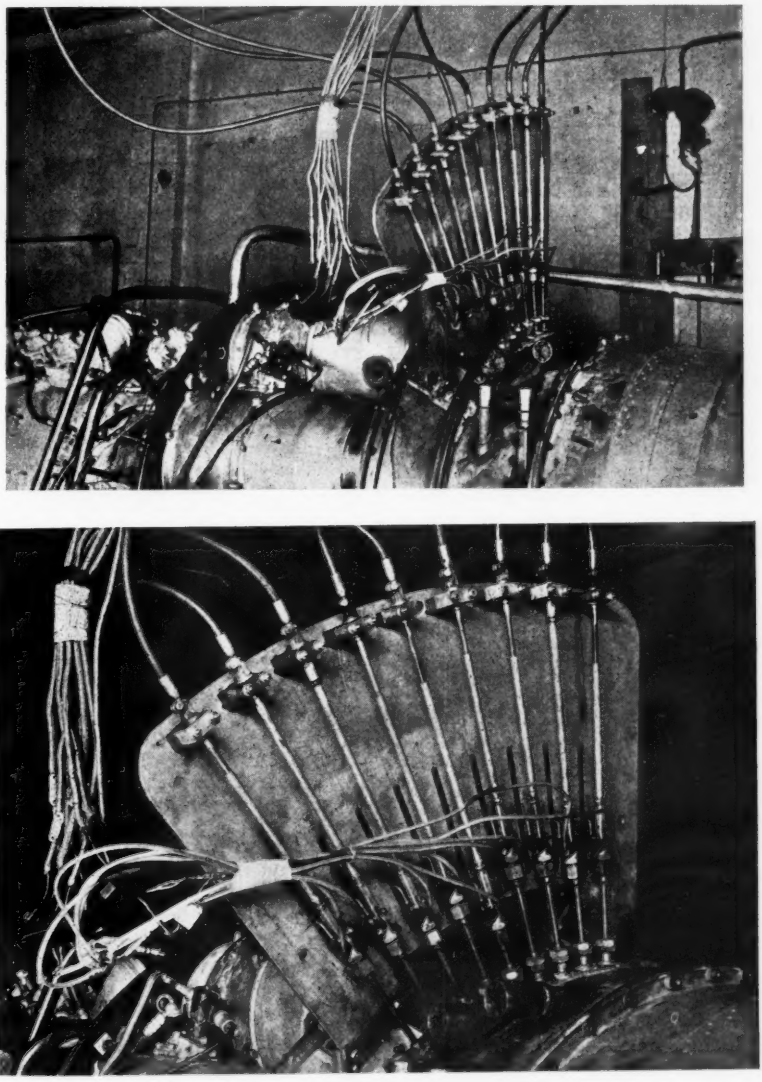


Fig. 9.
Engine tests for combustion chamber exit temperature traverse.

was developed having a small spray orifice for the lower part of the range opening up to a larger orifice to satisfy the maximum flow conditions and so prevent excessive pump pressures.

The photograph on the right of Fig. 7 shows the improvement in the spray characteristics of this burner and Fig. 8 shows comparative curves for the combustion stability over a wide range of operation. The modified burners also showed a marked improvement on starting and re-lighting engines in flight.

There are numerous other applications of the flash tube in present-day testing technique.

4.3. Temperature distribution

The combustion chambers' responsibility does not end at producing merely 100 per cent. combustion efficiency, but it must ensure that the temperature pattern at the turbine blades is the best possible to avoid creep failures. This does not necessarily mean that the temperature should be uniform along the length of the blade and it is usually preferable to have higher temperatures at the tip and lower temperatures at the root where the blade stress is highest. This is a normal routine test on the combustion rig but should also be carried out on the main engine. Fig. 9 shows the necessary apparatus fitted to an engine and Fig. 10 shows the apparatus in more detail.

It consists of nine doubly-shielded thermocouples, each of which can traverse radially the combustion chamber discharge nozzle which is ahead of the nozzle guide vanes. The control of the traversing arrangements

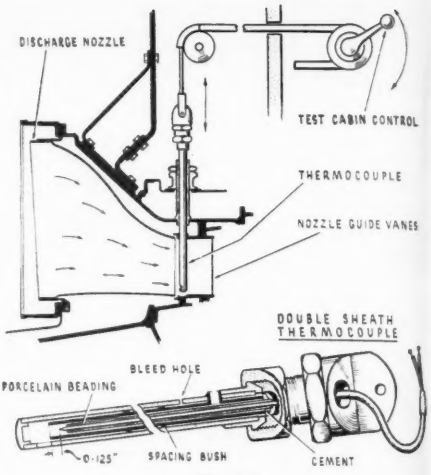


Fig. 10.
Combustion chamber exit temperature traverse.

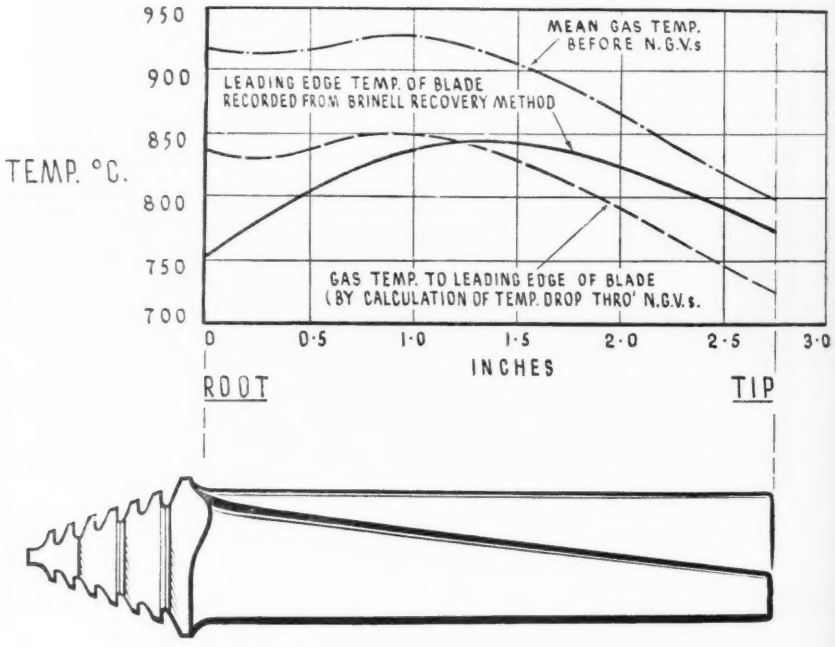


Fig. 12.
Turbine blade temperature deduced from temperature measurements before the N.G.V.s and from Brinell recovery method.

is done from the test cabin. Fig. 11 shows a typical example of a temperature traverse and is again given in the form of a celluloid model in which the ordinates represent the temperature. The mean radial temperature is shown in Fig. 12 which is in the form that the rotating turbine blade knows it.

In order to arrive at the blade temperature it is necessary to make a calculation of the temperature drop, and this is also shown on the curve.

This is an example of an indirect measurement and, as a further check on the accuracy, the actual blade temperature can be determined by the Brinell hardness recovery method. In this case it is necessary to fit a turbine with a few specially tempered blades and to run a steady test of approximately half an hour's duration.

The test blades are then removed and hardness checks taken over the whole surface of the blades and temperatures determined and so on. Plotting this on the previous diagram it is seen that the more direct measurement of the blade temperature under steady conditions is in reasonable agreement with the temperature deduced from the discharge nozzle traverse.

The calculated stress along the length of the blade will now be plotted on this diagram;

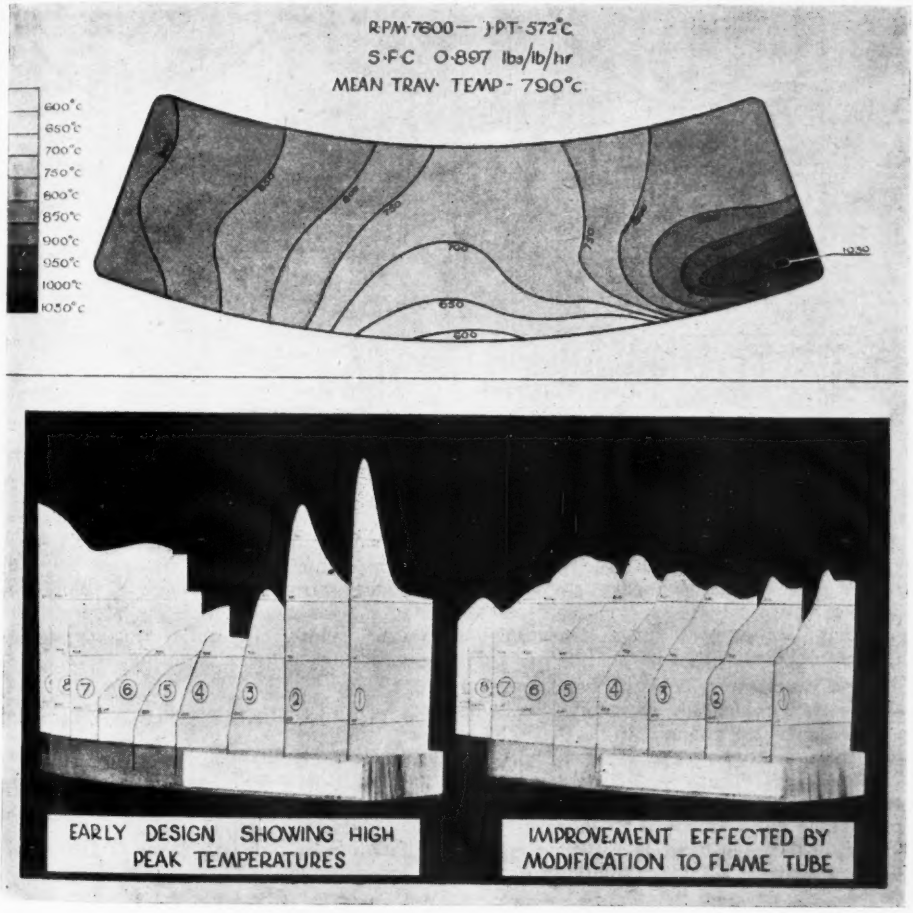


Fig. 11.
Engine tests of combustion chamber exit temperature traverse.

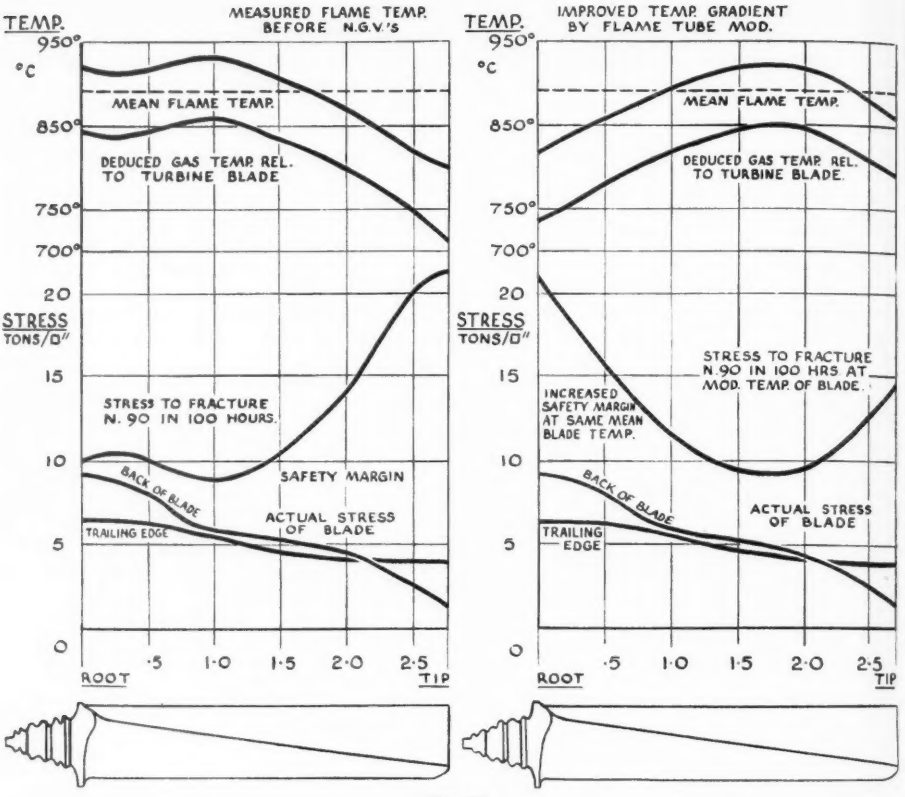


Fig. 13.
Improvement in blade life by flame tube modifications.

also, from the creep properties of the blade material can be plotted the stress to cause creep failure in 100 hours for the temperature of the blade at the different stations. The distance between these two curves represents the margin of safety. This is shown on the left-hand side of Fig. 13.

Close examination of these curves suggests that a greater margin of safety could be achieved by arranging for the higher temperatures to be nearer the tips of the blades. By certain modifications to the tertiary holes in the flame tube the temperature along the blade was changed to that shown in the right-hand side of the diagram and it can be seen that the margin of safety is now greater than before. Advantage of this improvement can be taken and the mean flame temperature raised, with a consequent improvement in performance of the engine.

The thermocouples used in this traverse gear can be replaced by total head tubes, and a complete survey made of the total pressure in front of the N.G.V.'s. This data, used in conjunction with the pressure plot at the compressor outlet duct, gives the pressure loss in the combustion system.

5. TURBINE—MECHANICAL TESTS

In order to obtain high efficiency from the turbine it is usually necessary to work at fairly close tip clearances and these clearances are bound to vary over the different operating conditions of the engine. It is desirable, therefore, to have complete knowledge of these variations without waiting for the indirect evidence of blades fouling the casing and then trying to deduce under which running condition the trouble happened.

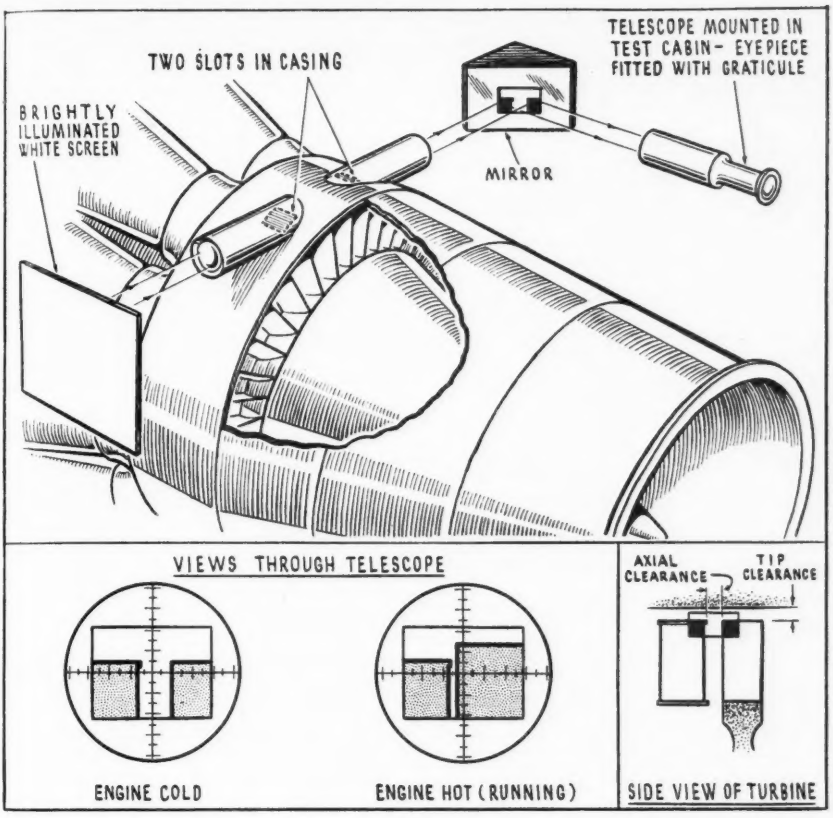


Fig. 14.
Principle of optical measurement of turbine clearances.

Two methods have been successfully employed: (*a*) the visual method and (*b*) the floating pin method.

(*a*) The visual method consists of cutting slots or windows in a suitable position in the shroud ring so that a shadow graph of the blade tip in relation to the shroud ring or nozzle guide vanes can be obtained. Gas leakage through these slots is prevented by means of quartz windows, and a powerful light is shone through the aperture and the beam reflected from a mirror into a remote telescope located in the test cell. A suitable scale can be fitted in the eye base of the telescope and a shadow of the blade, in relation to the shroud, can be observed while the engine is running. With the magnification in the telescope it is possible to read changes of clearance of the order of two thousandths of an inch. The changes of clearance can be comfortably observed over a wide range of operating conditions of the engine, such as accelerations, maximum power conditions, suddenly shutting down and so on. The layout of this apparatus is shown in Fig. 14 and by this method one is clearly able to arrive at the safe static clearance allowance for the blades.

Again, if abnormal changes of clearance occur, one has gone a long way to attacking the problem by precise knowledge of the conditions in which they occur.

(*b*) The floating pin method consists of a probe operated by an electric motor. An electrical contact is arranged which reverses the travel of the probe upon the lightest touch of the blade and reverses its motion.

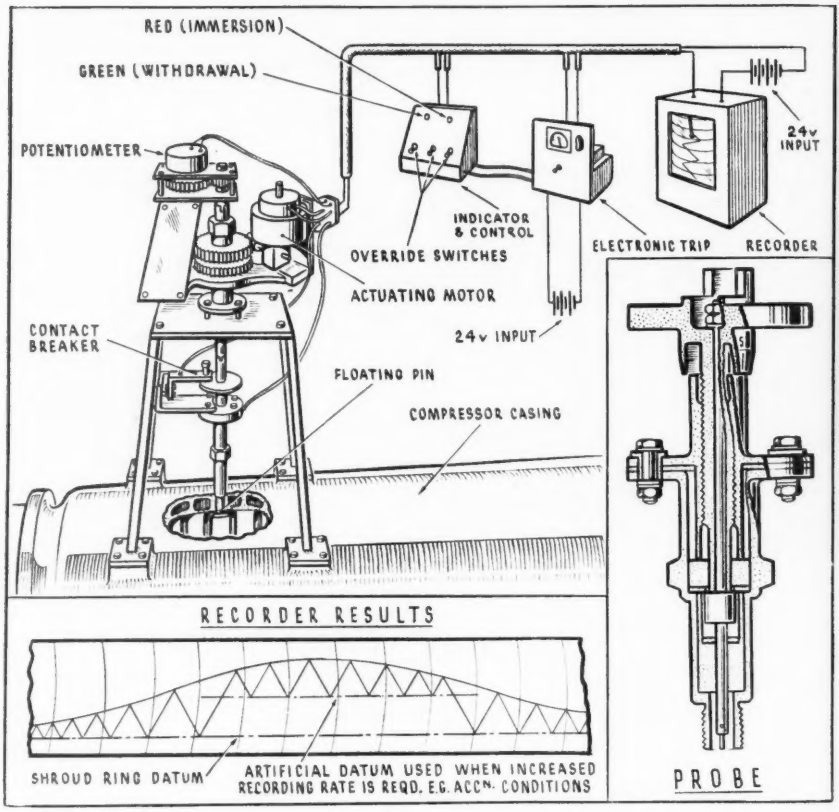


Fig. 15.
Measuring of compressor tip clearance.

The travel away from the moving blade is again reversed at any convenient predetermined distance.

The pin, however, floats in a position in which it just contacts the blade and, therefore, can be used to determine the clearance at any instant.

This method is excellent for determining radial clearance, but is not quite so easily used for determining axial movements of the blade.

Figures 15 and 16 show this apparatus in some detail, and the electrical circuit for its operation.

This apparatus is very suitable for measuring blade tip clearances on axial compressors and Fig. 17 shows it assembled for this purpose. An example of the variation in clearance over the speed range of the engine is shown on this diagram.

Measurements of this type are extremely valuable when considering such "boosting" schemes as methanol injection.

5.1. Turbine—Examination of Gas Flow Conditions on an Engine

It is often desirable to make a survey of the gas flow conditions at the turbine when operating on an engine. This provides comparisons of actual and design conditions and another means of co-relating engine and rig operating conditions.

The Traversing Yaw Meter, used for this purpose, is illustrated in Figs. 18 and 19. It is somewhat similar to the combustion temperature traversing gear, previously

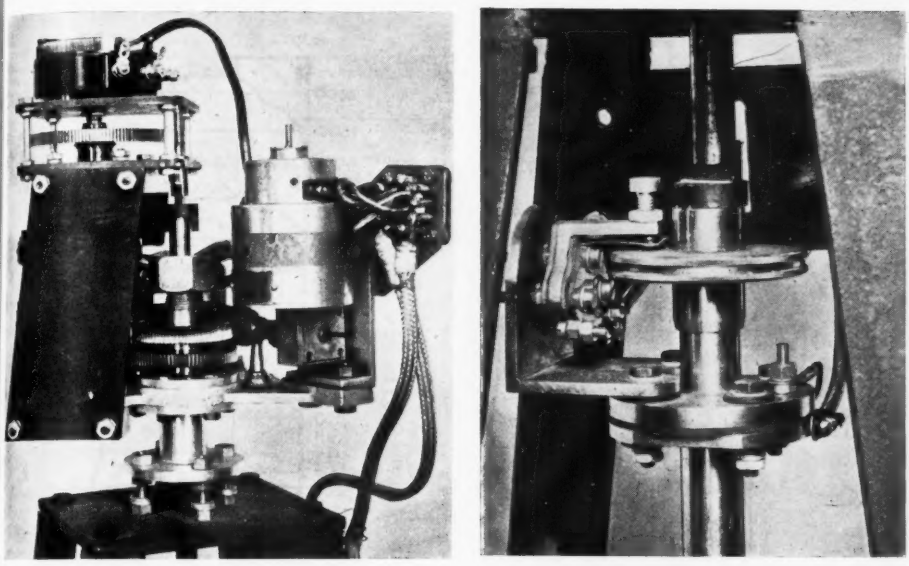


Fig. 16.
Compressor tip clearance measuring apparatus.

shown, except that it is operated by two reversible electric motors both in yaw and linear travel.

The readings are taken and the operation of the instrument is done from the test cabin.

An example of the data obtained from this apparatus is shown in Fig. 20.

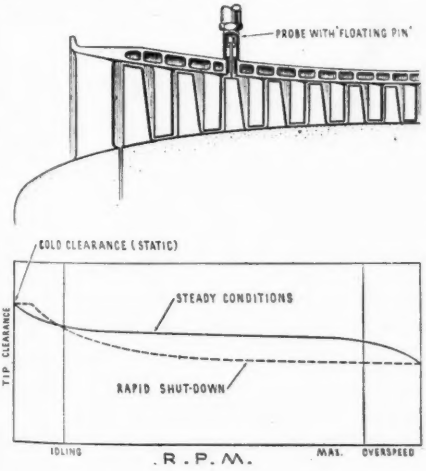


Fig. 17.
Measuring of compressor tip clearances.

6. FLIGHT TESTING

Flight testing forms an important part of the development programme, in fact, it should be regarded as an essential item of test before a new type of engine reaches the production stage.

It is now common to use a "Flying test bed" quite early in the development programme, and the Avro "Lancaster" is a popular machine for this purpose. The test engines are installed in the outboard positions while the normal inboard piston engines are retained.

This arrangement has several advantages. It affords a little more latitude in the test of control systems, relighting systems and so on, because loss of an engine in flight is not such a hazard. It also permits flying on the "test engines" alone, when a better picture of the general handling, synchronisation and so on of the engines can be obtained.

The type of data which can be obtained from a "flying test bed" falls, roughly, into the categories described in the next four sections.

6.1. Engine performance calibration

The complete calibration of an engine over its full operational range can be fairly

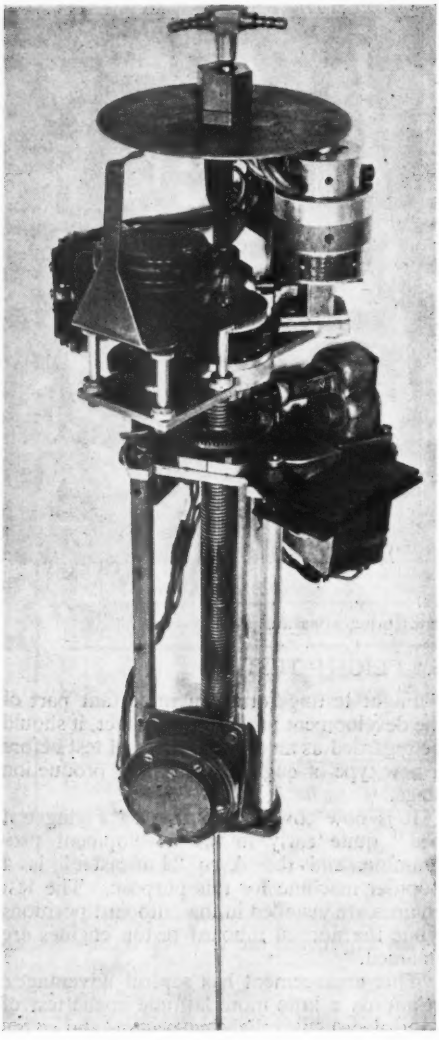
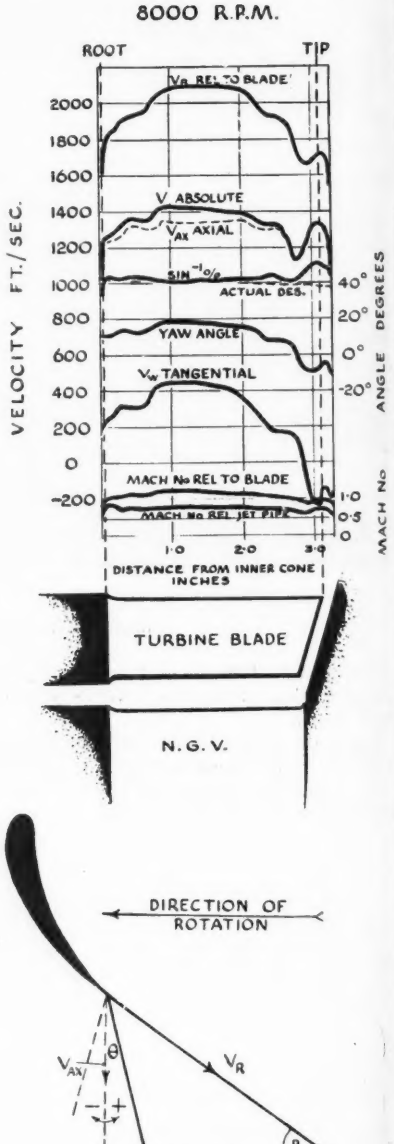


Fig. 18.
Turbine exit traverse—electrical yaw meter.

accurately assessed with relatively simple equipment. The fact that the "flying test bed," referred to earlier, is limited in altitude to about 36,000 feet, and in speed to about 300 m.p.m., does not present a serious handicap. The testing can be so arranged that the data which can be collected within these limits can be analysed, with a fair degree of accuracy, to cover a wide range of operation.



V = Absolute velocity
V_R = Vel. rel. blade
V_{AX} = Axial vel.
V_W = Whirl vel.
U = Blade vel.
θ = Yaw angle
B_R = Exit angle rel. to blade

Fig. 20.
Turbine exit traversing yaw meter.

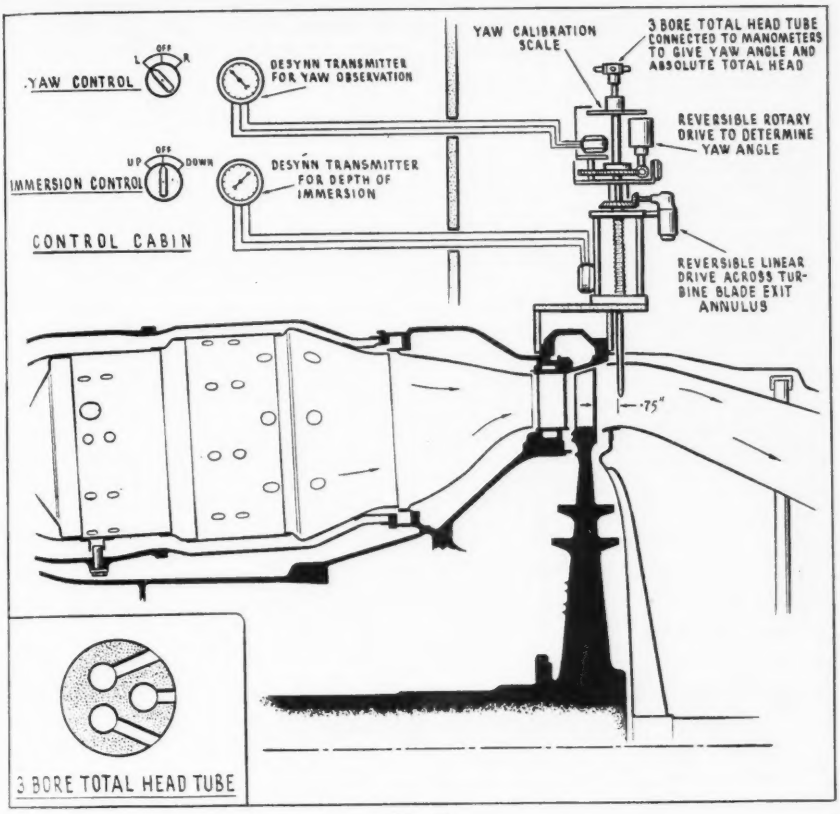

YAW CONTROL
L OFF R
DESYNN TRANSMITTER FOR YAW OBSERVATION
YAW CALIBRATION SCALE
3 BORE TOTAL HEAD TUBE CONNECTED TO MANOMETERS TO GIVE YAW ANGLE AND ABSOLUTE TOTAL HEAD
REVERSIBLE ROTARY DRIVE TO DETERMINE YAW ANGLE
IMMERSION CONTROL
UP OFF DOWN
DESYNN TRANSMITTER FOR DEPTH OF IMMERSION
CONTROL CABIN
REVERSIBLE LINEAR DRIVE ACROSS TURBINE BLADE EXIT ANNULUS
·75"
3 BORE TOTAL HEAD TUBE

Fig. 19.
Turbine exit traversing yaw meter.

Modifications to compressors, turbines and such like, can be tested under altitude conditions to observe the effects on performance.

At a later stage in the engine development the altitude calibration should be repeated in the aircraft types for which the particular engine is scheduled. This will then cover air intake effects and any effects from the lower Reynolds number at high altitudes.

It is desirable that published engine performance data should be confirmed by flight calibration.

6.2. Functional testing

This covers the general handling of the engine and behaviour of control systems, combustion systems, oil and fuel systems and so on.

From the general performance calibration, as described in the previous Section, the engine requirements at various speeds, altitudes and temperatures, will be known and a sound basis is available for applying the necessary corrective measures to control systems, should they fall short of requirements.

6.3. Mechanical

This comes into the endurance testing class and is mainly useful in investigating any mechanical troubles not encountered on the test bed which may be brought to light by high altitude operation. It may be taken as a general rule that an engine in flight will not escape any defects which have been manifest on the test bench but, in addition, new defects may come to light. For example,

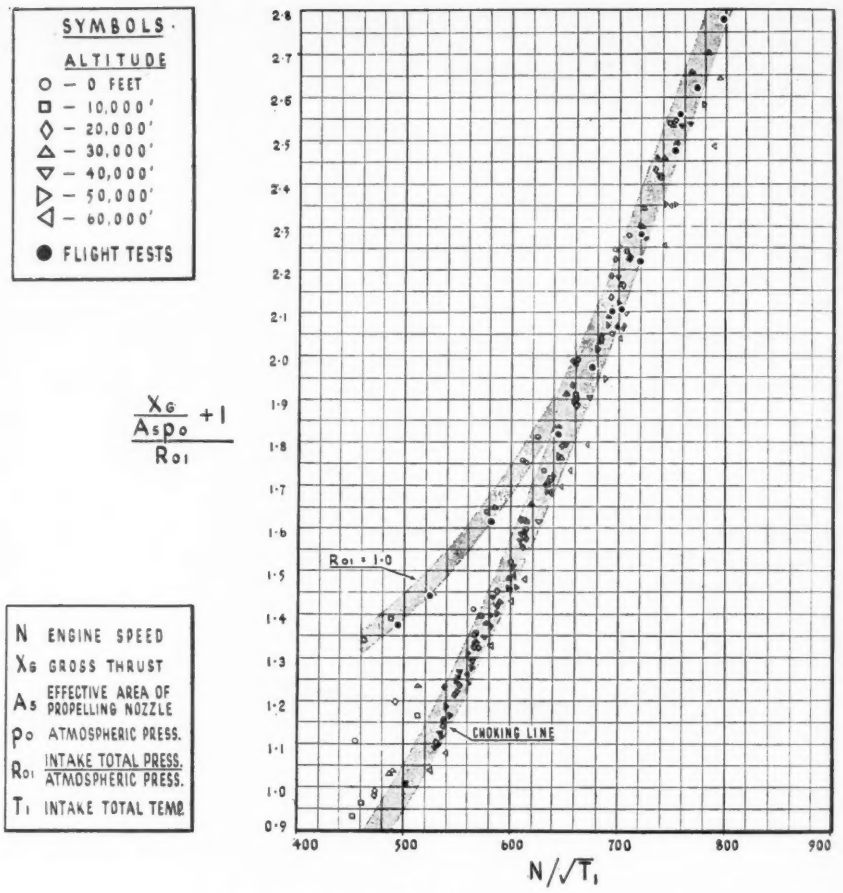


Fig. 21.
Comparison of thrust measured in altitude test chamber and computed by flight test method.

frequent re-lighting at high altitude may have adverse effects on flame tubes, N.G.V. and turbine blades.

6.4. Method of altitude calibration

It would appear that flight testing is an attempt to do what should rightfully be done in an altitude chamber. This may be true to a certain extent due to the non-availability of suitable capacity altitude chambers in Great Britain at the present time. It is considered, however, that if flight testing is carefully carried out the results of a full engine calibration will approximate very closely in accuracy, if not equal, those obtained in an altitude chamber.

Both methods overlap to a large extent but each has its own particular field of usefulness and they should be regarded as complementary to one another and not as alternatives.

The chief difference is that in the altitude chamber the thrust is measured directly, whereas in flight it is computed from pressure and temperature measurements in the jet pipe, that is to say, by using the final nozzle as a flow measuring orifice. Air mass flow is also computed from jet pipe readings in flight and the same method is usually adopted in the altitude chamber.

The determination of thrust in flight depends upon measurements of the total

pressure or static, temperature within the jet pipe upstream of the propelling nozzle and a knowledge of the effective area of the nozzle.

The theoretical relationship of thrust and these factors is well established and is based on the assumption of uniform one-dimensional flow along the jet pipe and across the final nozzle. Therefore, the only serious error in thrust computed by this method arises through departure of the actual flow in the jet pipe nozzle from uniform conditions.

In other words the actual readings obtained may not be representative of the true mean values.

This error can be eliminated by a test bed calibration of the engine and jet pipe under conditions in which the actual measured thrust is related to the jet pipe pressures and temperatures, and the "effective" area of

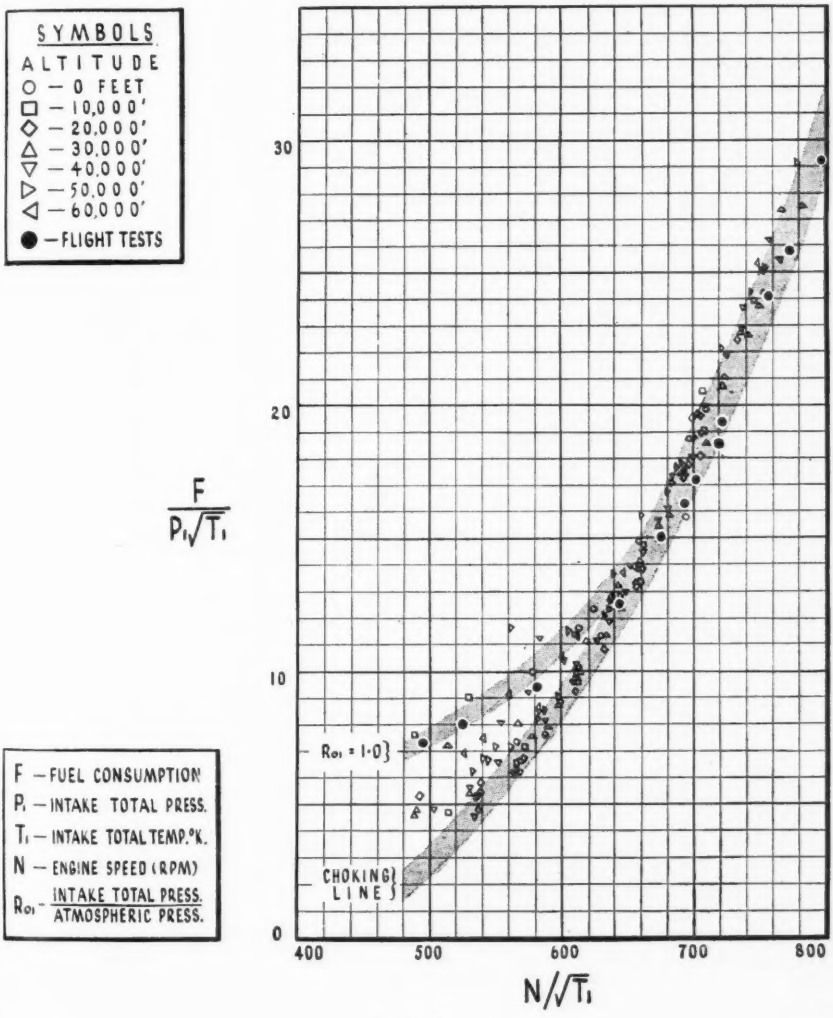


Fig. 22.
Comparison of fuel consumption measured in an altitude test chamber and in flight.

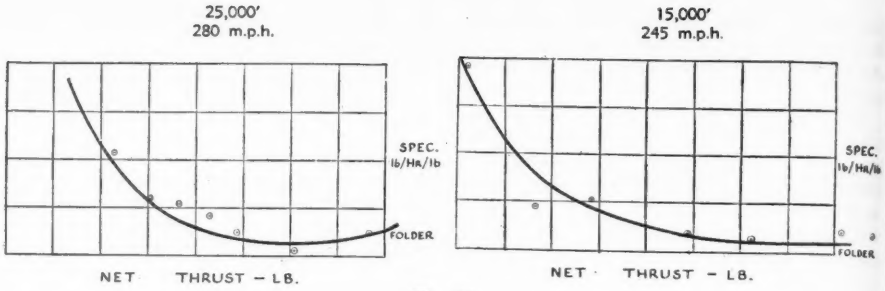


Fig. 23.
Comparison of flight test results with the normal performance predictions.

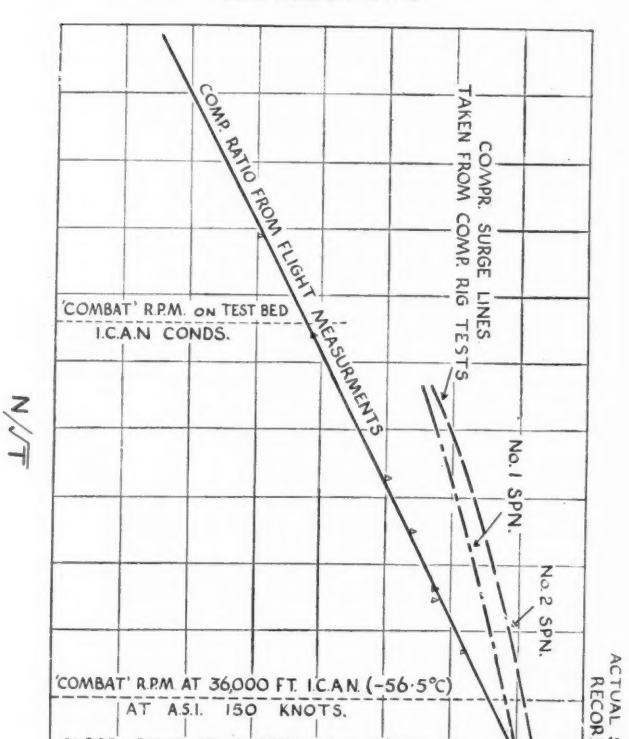

COMPRESSION RATIO
N/√T
COMP. RATIO FROM FLIGHT MEASURMENTS
COMPR. SURGE LINES TAKEN FROM COMP. RIG TESTS
No. 1 SPN.
No. 2 SPN.
'COMBAT' R.P.M. ON TEST BED I.C.A.N CONDS.
'COMBAT' R.P.M AT 36,000 FT. I.C.A.N. (-56·5°C) AT A.S.I. 150 KNOTS.
SURGE POINT AT COMBAT R.P.M. 36,000 FT. A.S.I. 150 KNOTS AND AMBIENT AIR TEMP. -64°C
IMPROVED SURGE POINT FOR SAME CONDN PERMITS AMBIENT TEMP. DOWN TO -74°C
ACTUAL SURGE POINTS RECORDED IN FLIGHT.

Fig. 24.
Measurement of surge points in flight by over-speed methods.

the propelling nozzle as opposed to the "geometric" area is determined.

The ratio of these two areas is generally known as the "contraction" coefficient, but in actual fact it is somewhat more than this as it contains the correction factor for the pressure and temperature readings, which in themselves may not be truly representative of the mean conditions.

With regard to this last item, it is usual to have made a complete pressure and temperature traverse across the jet pipe in order to locate the test pressure and temperature tapping points (either single or multiple ones) at positions reading mean values. A range of engine speeds should be covered to ensure that there is no serious shift in the pattern of the traverse.

The test bed calibrations must be taken up beyond conditions where the final nozzle is choked and theoretically, the contraction coefficient should remain constant as the pressure ratio across the nozzle increases beyond the choking value.

Unfortunately we are unable to extend the test bed calibration up to pressure ratios much beyond the choking value, but as far as we can go the coefficient remains substantially constant. Pressure ratios of 2.2/1 can be reached on the test bed whereas in flight values of 4 to one can be reached.

The chief uncertainty of thrust determination from jet pipe measurements at high pressure ratios now rests upon the assumption of constant area coefficient. It is here that the high altitude test chamber can supply data on this subject.

From analysis of the data available it does appear that there is a slight increase in the contraction coefficient of the order of two per cent. up to approximately 3 to one pressure ratio which means that thrust values on the previous assumption, *i.e.* constant value of contraction coefficient, are slightly pessimistic.

Considering all the data available it appears that the thrust of an engine in flight can be determined with a very fair degree of accuracy. The jet pipe method, carefully done, would seem to be no less accurate than determination of aircraft speed at high altitudes by the normal pitot tube.

In justification of flight calibration Fig. 21 shows a comparison of results obtained in a high altitude test chamber and those obtained from the flight methods previously described. It will be seen that there is very close agreement. Similar curves for fuel flow are given in Fig. 22, and Fig. 23 shows how these tests agree with the normal performance predictions.

Other useful data which can be obtained is confirmation that the surge point of the engine is safely outside the engine operating range. It is well known that, as the intake temperature falls, the surge line of the compressor converges on the working line of the engine and at the point of intersection the engine "surges." Such data is normally obtained from the compressor test rig and the turbine/compressor characteristics are so matched that the intersection is outside the desired working range. Actual confirmation of this cannot be obtained on the test bed.

The method is to fly the aircraft at approximately the tropopause and over-speed the engine until surge is encountered. The lower the air temperature and the lower the aircraft speed, the less over-speeding required. Having determined the value of the "corrected" speed, *i.e.* $N/\sqrt{T}$, the air temperature and aircraft speed at which the engine would surge at its operational r.p.m. can be calculated.

Figure 24 is an actual example of this method and shows how the surge point was raised by compressor modifications.

Figure 25 is a specimen of flight test results showing their overlap of the test bed readings. The points plotted were obtained from several flight tests on different days and show a very small degree of scatter.

7. STRAIN GAUGE TESTS OF TURBINE BLADES

The use of wire-wound strain gauges for measuring strains on stationary and slow moving parts is well known.

They were used on rotating gas turbine impellers by Rolls-Royce Ltd. in 1943 for investigating the causes of impeller failure. This involved the development of slip rings that would carry electric current to an impeller running at speeds up to 17,000 r.p.m. The arrangement originally employed silver graphite brushes in contact with stainless steel S.9 slip rings.

In order to keep the brushes in contact with the rings at the very high speeds involved, pressures had to be applied equal to approximately ten times that recommended by the makers of the brushes. The carbon and silver dust that came off the brushes, due to the rapid wear, had to be removed from the vicinity of the slip rings by air blast, which

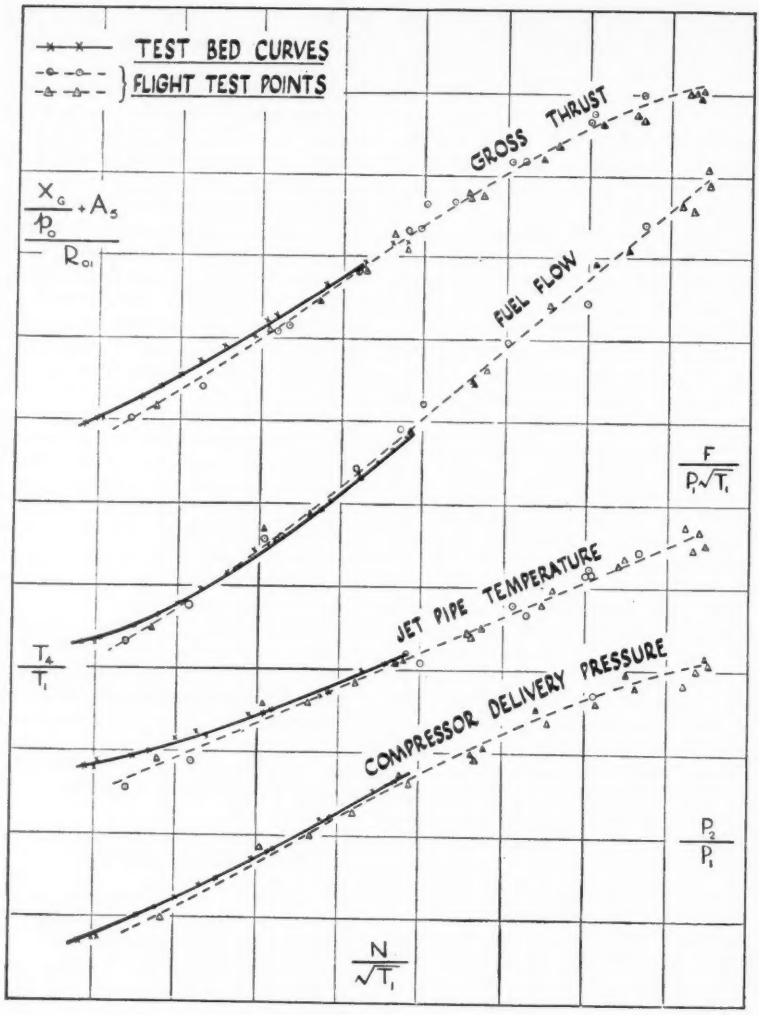


Fig. 25.
Example of engine performance calibration by flight test method.

also served to cool the rings. Nevertheless very satisfactory "signals" were obtained by these rings as long ago as 1943.

Since then considerable progress has been made and silver graphite brushes have been entirely superseded by mercury slip rings. The measurement of stresses in rotating centrifugal impellers, or axial compressor blades, is an every-day occurrence.

Recently strain gauges have been applied to the much more difficult problem of investigating the frequency, mode and amplitude of vibration of turbine blades in running engines. Fig. 26 shows, diagrammatically, the arrangement of the apparatus for this work.

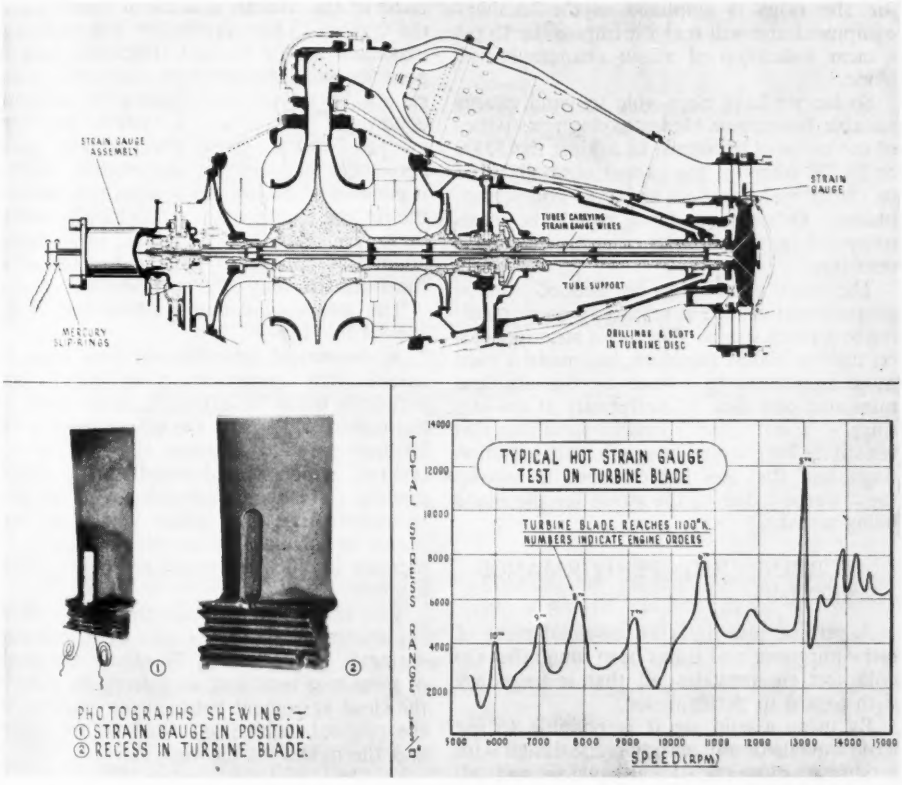
This development has involved two main problems. First it was necessary to find an adhesive, having the necessary electrical insulating properties at high temperatures, that would adhere to the blade with sufficient tenacity not only to resist the centrifugal force

equivalent to 10,000 *g*, but to ensure that the wire of a gauge was stretched and shrunk by the blade during vibration.

The coefficient of expansion of the cement had to be sufficiently near to that of the blade material to avoid cracking due to contraction on cooling.

The heat treatment of cement must be below the temperature that would do permanent damage to the blade material. Using a "Nimonic" blade it is undesirable to exceed 900°C. in stoving the gauge in position, yet the gauge must work and remain in position at temperatures of, say, 800°C. Unfortunately the cements that have been developed for this purpose are corrosive and attack the material of the wire. This makes it impracticable to use very fine gauges of wire (the minimum used so far is 0.002 in.) and the overall resistivity of the gauge, therefore, is very low, compared with the sort of gauge that can be used on a cool part where non-corrosive polymerising adhesives may be employed. Fig. 26 shows a turbine blade prepared for the strain gauge and a strain gauge fitted.

Amplifiers having an amplification as high as half a million bring problems of their own due to instability and, what is more important, the tendency to pick up electrical interference from the considerable electrical equipment on the test bed. It is not practical to screen completely a strain gauge fitted to a turbine blade and its leads, and amplification of half a million cannot be used when one side of the circuit and amplifier is earthed, as is the conventional practice.


STRAIN GAUGE ASSEMBLY
STRAIN GAUGE
TUBES CARRYING STRAIN GAUGE WIRES
TUBE SUPPORT
MERCURY SLIP RINGS
DRILLINGS & SLOTS IN TURBINE DISC
PHOTOGRAPHS SHEWING:—
① STRAIN GAUGE IN POSITION.
② RECESS IN TURBINE BLADE.
TYPICAL HOT STRAIN GAUGE TEST ON TURBINE BLADE
TURBINE BLADE REACHES 1100°K.
NUMBERS INDICATE ENGINE ORDERS
TOTAL STRESS RANGE (LBS/SQ IN)
SPEED (R.P.M.)

Photographs showing: (1) Strain gauge in position; (2) Recess in turbine blade.

Fig. 26.
Strain gauge applied to turbine blades.

Very special equipment "balanced to earth" has been developed, *i.e.* equipment in which both the leads from the strain gauge are insulated. Any tendency for these leads to pick up interference from the electrical equipment in the test house tends to be equal and opposite in the two leads.

All these problems have been overcome and the stage has been reached where strain gauge measurements on rotating turbine blades are taken almost as a matter of routine. Very soon these tests will be made in flight. Fig. 26 also shows a typical example of the results obtained by means of this apparatus.

This leads to the second main problem. The sensitivity of a gauge fitted to a turbine blade is low, and it is necessary to employ slip rings whose resistivity is extremely constant, since any change in voltage drop at the slip rings is amplified in the ancillary equipment and will make it impossible to get a clear indication of strain changes in the blade.

So far we have been able to wind gauges suitable for turbine blades having resistivities of the order of 70 ohms, as against the 5,000 or 10,000 ohms of the gauges normally used on centrifugal impellers and axial compressor blades. Other things being equal, the sensitivity of gauges varies directly as their resistivity.

The sensitivity may be defined as the proportional change in resistivity corresponding to a given strain. The use of strain gauges on turbine blades therefore, has made it even more important to reduce to the absolute minimum any lack of uniformity at the slip rings. Even very small variations in resistivity here would magnify half a million times and they are liable indeed to swamp the "signal" due to the strain on the blade being tested.

8. TURBINE RIG—PERFORMANCE TESTING

A turbine test rig is an essential piece of test equipment, and it has been found that the cold test rig provides all that is necessary with regard to performance.

By using a cold rig it is possible to use scale models of any aerodynamic design with a simple mechanical construction and all parts, including blades and nozzle guide vanes.

The use of scale models reduces the size of plant necessary for testing turbines. A rough estimate shows that to test a full-scale turbine of the latest type with hot gas would require a plant and power at least three times that of the cold model rig.

The plant for testing model turbines comprises two compressors of different capacities, each giving a pressure ratio of 3 to one. One supplies air to the turbine at a positive pressure and the other sucks away the exhaust to give a high pressure ratio across the turbine. Two 2,000 h.p. units are used to drive the compressors.

On this plant turbines can be tested up to 8 to one pressure ratio, which is needed to cover turbo-propeller engines at altitude conditions.

Naturally certain allowances have to be made in relating the testing conditions on the rig to the operating conditions on the engine, due to the difference between the specific heats of the cold air and the hot gas used on the engine. The relationship is complicated inasmuch as the various functions, such as pressure ratio, temperature ratio and so on, cannot be related simultaneously to engine conditions. However, a system has been evolved which gives exceptionally good agreement between rig and engine. Briefly it consists of basing the comparison between the rig and engine upon geometrically similar vector triangles for the turbine, under which conditions correction factors for the other functions are of a small order.

The following example shows one of the uses of the rig:-

A theoretical investigation was made to assess what improvement in engine performance could be expected by re-design of the turbine.. To raise the efficiency it would be necessary to increase the size of the turbine, which would result in a weight penalty. This would naturally affect the gain in performance and, while it was an easy matter to calculate the increase in weight, the increase in efficiency could not be so readily assessed.

Two models were made, therefore, one of the existing design and one of the increased diameter turbine. Fig. 27 shows the result of these two tests and an interesting point is the close agreement between the efficiency of the original turbine as tested on the engine and the model on the rig.

8.1. PHOTOELASTIC STRESS ANALYSIS

Strictly speaking, this subject is out of place in this paper, but it is such a valuable

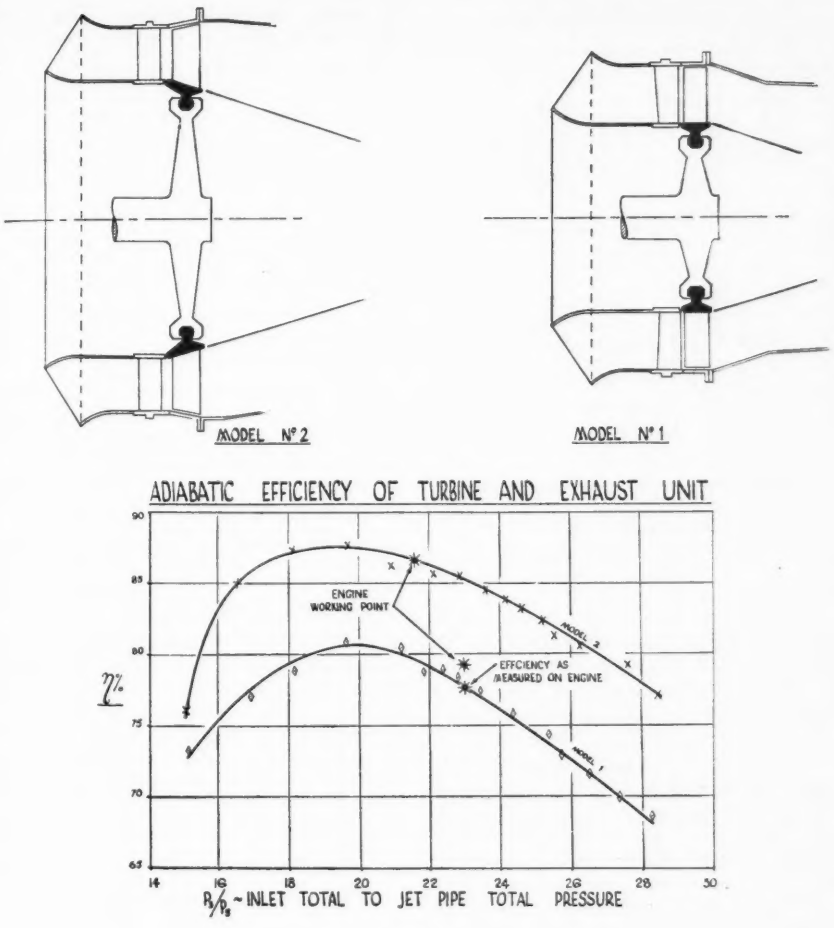


Fig. 27.
Turbine rig performance tests.

aid during the development of an engine that brief reference to it is considered permissible.

Photoelastic analysis of highly stressed parts in an engine is used almost daily, and its contribution to reliability is not to be overlooked.

Two examples of its use are shown in Figs. 28 and 29. The first shows how modification to the nut of a bearing cap reduced the stress concentration in the thread fillet of the stud and eliminated fatigue failure.

The second example shows an improvement in the fir tree root fixing of a turbine blade resulting from photoelastic work.

9. MISCELLANEOUS ITEMS

WIND TUNNELS

The wind tunnel has several applications in the development of the aero-engine and power plant. For the jet engine, one of its uses is in the investigation of air intakes. In some instances the air intake duct can be of considerable length and of complex shape and

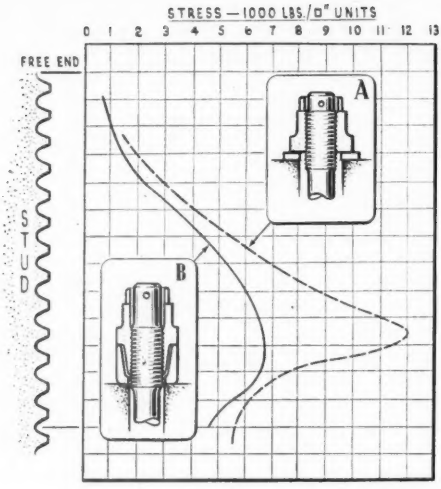


Fig. 28.
Photoelastic stress analysis.
Reduction in stud stress concentration by redesign of nut.

the wind tunnel, in this case, is used for sucking through a full-scale mock-up of the duct. By this means the flow conditions at the entry of the compressor, together with the pressure losses, can be studied carefully.

A simple form of wind tunnel for this purpose is illustrated in Fig. 30. It consists of a Derwent jet engine inside a duct in which the air flow through the working section of the tunnel consists of air drawn in by the engine itself, and the additional air flow induced by the injector effect from the jet of the Derwent. This equipment is relatively cheap and possesses great flexibility as a piece of air flow equipment.

This apparatus can be used for quarter-scale models of various intake wing configurations, or full-scale intake duct tests.

In the particular equipment illustrated a Mach number of 0.78 can be reached in the working section of the tunnel, which has an area of 707 sq. in. A maximum air flow of 200 lb. sec. can be obtained in this tunnel.

10. UTILISATION OF TEST FACILITIES

The development period is often from two to three (or more) times as long as is taken to design the basic engine. The question likely to be asked is, why this long period?

It has sometimes been said that if the design were sound it would not be necessary to do so much development. This, of course, is a mistake. The design of a new project is based on all the knowledge available at the time, and the testing period is a manifestation of the gaps in that knowledge.

If an engine is to show sufficient technical advantage over its predecessor there are bound to be problems. They do not arise until the material has taken shape, and it is by means of testing that they are uncovered and we come to grips with them.

If an examination is made of the distribution of work over the various test facilities it is usual to find that bench testing accounts for the greatest share of time. Fig. 31 is an example of the time devoted to the different forms of testing relative to the test bed.

Cost is another factor which cannot be ignored and, if this is included in the picture (*see* Fig. 31), it will be found again that bench testing takes the lion's share.

These two very approximate examples have been given to stress the importance of obtaining the maximum value from testing. By making use of fuller instrumentation on engines on the bench it should be possible to make early diagnosis of latent problems and, in parallel with the engine testing, bring

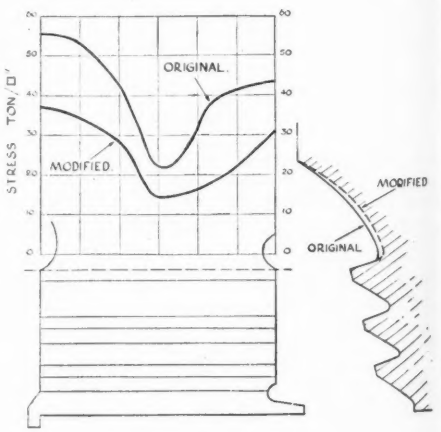


Fig. 29.
Reduction in stress of turbine blade root fixing.

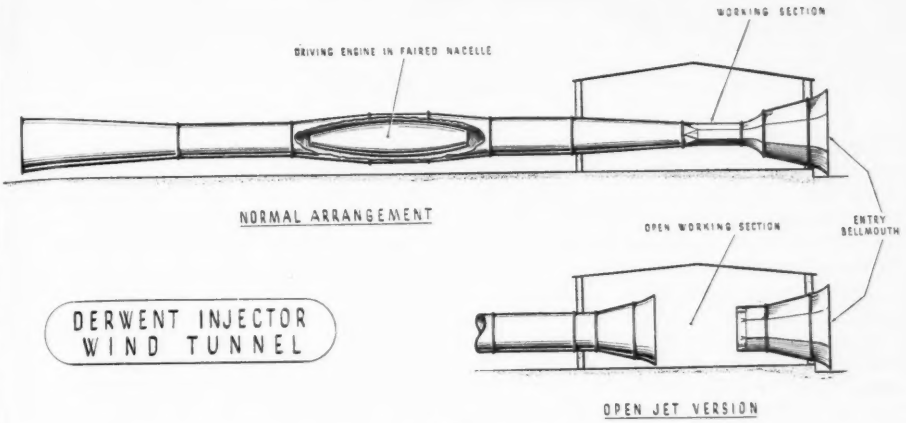
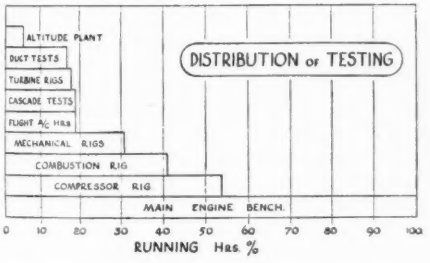


Fig. 30.
Derwent injector wind tunnel.

into play the various rigs to share in the attack.

By pressing this policy to the full the development time should be shortened and the cost decreased.



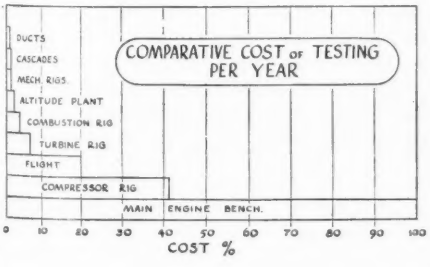


Fig. 31.

11. CONCLUSION

A few examples of testing methods have been described, but there are many others, far too numerous to cover in the space available.

The primary object has been to draw attention to the long and costly development period of an aero-engine and to offer suggestions, illustrated by simple practical examples, of means of shortening and cheapening the work.

To summarise, I would say the aims should be: —

(1) Fuller instrumentation of engines on the bench in the very early stages of running.

(2) Co-ordinating the various rigs with main engine conditions. For example, combustion rigs.

(3) Wider distribution of testing on to the rigs before too much "hardwear" is produced.

(4) Use of flight testing for establishing, or confirming, engine performance at altitude.

Finally, I wish to thank the Ministry of Supply for permission to present this paper, and Rolls-Royce Ltd., for the information contained in it.

DISCUSSION

Air Commodore F. R. Banks (Technical Manager and Chief Engineer, Associated Ethyl Co. Ltd., *Fellow*): The paper gave more valuable information than any other he had seen or heard, so far, on the problems of developing a gas turbine.

One of the most important things that had been done by the Company was to develop a system or procedure of flight testing which could provide the necessary answers and data, expeditiously, where a large and expensive altitude chamber was not available for engine tests. The flight testing procedure developed by Rolls-Royce should be extended and improved, so that important engine development was not held up by the lack of altitude chambers. He thought that there would be a limit to the size of altitude chamber which it was practical to build, and few countries would be able to finance bigger and better power stations for testing larger engines when they came along.

Was it possible to get accurate answers by testing large axial compressors under throttled conditions, when only about a third of the power necessary to drive them under atmospheric conditions was available?

Dr. E. S. Moult (Chief Engineer, The de Havilland Engine Co. Ltd., *Fellow*): In general, he agreed with Mr. Lovesey; they had seen the advances that could be made as the result of power plant development. The process was not purely a matter of getting an engine through its type test and into production, but also of progressively advancing its output during successive years. During the war the Merlin engine, which had started in service with an output of about 1,000 h.p., had been developed to well over 2,000 h.p. They had wondered whether, with the coming of the jet era, there would be equal advances in output from a given engine. It was interesting that whereas the first Vampire had flown at about 2,000 lb. thrust, nowadays the same engine was flown in the same aircraft at over twice that figure.

By the process of development the margins of safety in the original design were determined and balanced. By careful planning and by adopting methods of instrumentation and measurement, as described by the author, knowledge was increased and the development accelerated.

The Duple or Duplex burner had undoubtedly produced better atomisation, but it was only fair to say that it had also introduced some difficulties at the point of change-over from what might be called the pilot jet to the main jet. That was not of importance at sea level and at moderate altitudes, but it became important when cruising at great altitudes. In one arrangement the change-over was effected normally by a spring-loaded valve susceptible to burner pressure, and the operation depended on the strength of the spring; it was not unexpected, therefore, that the characteristics of those spring-loaded valves varied. The extent of the variations could be minimised by a flow distributor which was a built-in resistance in series with a burner orifice. Nevertheless, those inconsistencies were causing a little worry when operating at altitude, when the fuel pressures were very low; to some degree they offset the advantages of improved atomisation.

The effect of turbine temperature distribution on the blade stress safety factor was indicated in Fig. 13, but there were other factors affecting blade safety. The true safety factor must also involve some knowledge of the vibratory stresses at any particular condition of operation. For example, the right-hand diagram of Fig. 13 showed improved conditions at the root of the blade at the expense of a smaller margin from about the centre of the blade outwards. Whether the particular blade was safer or less safe would depend, he imagined, on the distribution and magnitude of the superimposed vibratory stresses.

The strain gauging of turbine blades was helpful in determining the vibration stresses, although it might be argued that the heavy cuts in the blade at the root for attachment of the gauge could modify the characteristics and weaken the blade. In practice critical vibrations also occurred farther out along the blade and, as with propeller blades, a fairly complete analysis of vibratory stresses was necessary, in addition to a knowledge of the vibratory stresses at the blade root.

Would the author explain why, in the example quoted, there was residual stress at the tip of the blade?

What sort of statistical accuracy had been attained in the measurements by strain gauges? His Company's troubles had been due to inconsistency, particularly as between individual blades. How many channels had the author found it possible to provide with his mercury troughs? It was desirable to have more than one, or more than a few. How many design changes had resulted directly from the strain gauging of turbine blades at their roots?

O. N. Lawrence (Joseph Lucas Ltd., *Assoc. Fellow*): It was a formidable task to regulate the air flow into combustion chambers, but it was necessary if good combustion efficiencies were to be obtained with a low overall pressure drop across the chambers. The problem was worse with early centrifugal blowers; then there had been violent pulsations of pressure and large areas of flow reversal even, but they had somewhat diminished in the newer centrifugal blowers with corner vanes. Axial blowers also presented some troubles but not quite of the same sort.

The outer casings of the early combustion chambers were made in stainless steel, and they had all broken. It was found that mild steel was a much better material than stainless steel for damping the vibrations.

Atomisation was a most complex subject. The Shell Company had started work by producing wax droplets for purposes of measurement, and that work had been followed up by his own Company. It had also attracted some theoretical study by Professor Sir Geoffrey Taylor at Cambridge, and quite a few papers had been presented recently on the subject.

He agreed on the difficulty and expense of providing a large altitude test chamber and plant at low altitude, but was surprised at Mr. Lovesey's statement that tests in altitude plant occupied more time than flight tests; he had been a member of a team which had made some tests on a German plant at Munich, from which some rather valuable results were obtained remarkably quickly.

Dr. B. F. Jakobsson (*Flygmotor*, Sweden, *Assoc. Fellow*): Mr. Lovesey had shown excellent agreement between the results obtained by different testing methods for the altitude calibrations of jet engines. He suspected, however, that there could be an inter-action between the gases coming out of the jet and the air flowing on the outside of the aeroplane. Fig. A illustrated this point.

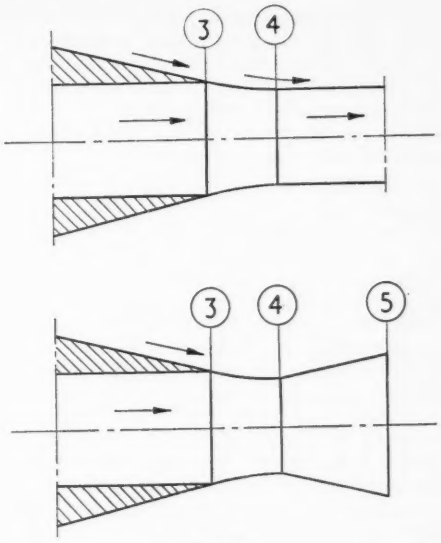


Fig. A.

The outside air in that case could not change direction immediately. Because of the outside stream of air, the engine jet would be contracted and would build up a pressure in the outlet (section 3), reaching the atmospheric pressure in section 4 which was behind the outlet. Section 4 was smaller than the outlet area. He suspected that the higher the aeroplane speed, the greater would be the contraction. That contraction meant higher thrust due to smaller outlet area, but it also meant higher turbine temperatures, which were dangerous for the blades.

The lower figure showed the jet at super critical pressure ratio in the jet pipe. Even there the Mach number unity was reached in the section 4 behind the outlet.

The figures showed that an engine with a fixed nozzle area had a variable air nozzle behind. Section 4 showed the true effective area, and as it varied with the aeroplane velocity it could not be determined either in normal test beds or in altitude chambers. Tests made in Sweden in connection with a new jet fighter seemed to show a contraction of about 0.95, which meant making a 5 per cent. correction in the gross thrust as calculated in the usual way, and the error in the net thrust could be even greater.

In the altitude chamber there was not the same outside air inter-action as there was in flight and therefore, the value of thrust measurements in those chambers was somewhat uncertain. Other methods for determining flight thrust should be chosen if accurate values were to be obtained.

In aeroplanes with long nacelles of small diameter, as on the Meteor or the Canberra, the jet contraction ought to be quite small; but in aeroplanes with short and thick nacelles, such as the Vampire, the contraction could possibly be of importance.

He congratulated Rolls-Royce Ltd. on having achieved the specific fuel consumption of 0.897 lb./lb./hr. shown in the top of Fig. 11.

Dr. A. W. Morley (D. Napier and Son Ltd., *Assoc. Fellow*): A question in the minds of many concerned the difference between the gross and the net thrust as estimated from flight work. The curves which had been shown were for the gross thrust, whereas the specific fuel consumptions were on a net thrust basis. He believed that a big argument in favour of an altitude test tunnel was that it could be used to determine net thrust. How had Mr. Lovesey computed this thrust from flight tests?

Mohamed Saeed: Were the engines tested for performance in low temperature conditions? Were Arctic climate conditions considered in the designing of an engine and performance under low temperatures satisfied before the engine finally went into production?

J. L. Edwards (Combustion Research Engineer, The de Havilland Engine Co. Ltd.): He was interested in the pictures of combustion chambers, but found it difficult to believe that the modification made to the air flow distribution provided a complete cure for the mechanical troubles experienced. From such experience as he had, difficulties with distortion of combustion chambers were seldom attributable entirely to poor air flow at entry, although those air flow conditions undoubtedly played a major part in determining metal temperatures. In connection with the modifications to combustion chambers, had Mr. Lovesey investigated the effects of skin cooling and if so, did that obviate or mitigate the over-heating effects of faulty air entry?

Would Mr. Lovesey say that the combustion chamber of orthodox design suffered from vibration troubles through excessive rigidity, and could he overcome the dangers of thermal distortion by building sufficient flexibility into the chamber to allow it to flex without doing any permanent damage?

The improved atomisation provided by the Duple or Duplex type of burners undoubtedly effected a great improvement in combustion efficiency, but there were two other factors which should be taken into account—first, the effects of variations in cone angle, and second, the effects of "penetration" energy of the droplets in the air stream. To obtain good combustion, obviously the fuel must be spread in such a form throughout the air that each droplet of fuel found the necessary oxygen to combust it. It was quite possible under certain conditions, when fuel was sprayed in very fine form into an air stream —they were always trying to improve the degree of atomisation—that the energy of the individual droplets was such that they would not reach the outermost film of air, the result being that unburned, or partially burned, fuel would be carried past the turbine, with obviously adverse effects on the combustion efficiency.

The two factors, very fine atomisation, and penetration energy were somewhat incompatible, and he would like Mr. Lovesey's comments.

Did the illustrations shown give a true representation of the instrumentation used for the measurement of mass flows and performance in flight? The measurement of temperatures under low pressure conditions usually necessitated the use of a suction type of thermocouple; was such an instrument used? The measurement of a mean total pressure by a single instrument involved an assumption of uniform, or at least consistent, total pressure distribution over the measuring section, and he would like Mr. Lovesey's comments on that point. The problem was relatively easier on the Meteor, which had a good length of tail pipe, but in the Vampire, where the tail pipe more or less finished at the end of the inner cone, the measurement of total pressures and temperatures would be difficult because of variations in stream conditions across the nozzle. Had Mr. Lovesey had experience of flight testing where the tail pipes were very short?

S. Scott Hall (D.G.T.D.(A) Ministry of Supply, *Fellow*): Mr. Lovesey had said that his primary object had been to draw attention to the long and costly development period of an aero-engine and to offer suggestions of means of shortening and cheapening the work.

A glance at the financial figures emphasised the cost of engine development; could Mr. Lovesey foresee any reduction of the amount of time and money that had to be spent on engine testing? A reduction of that expenditure might have been expected with the turbine because of the reduction of power plant vibration and the effects of that on endurance; but there seemed to be nothing in the paper to indicate how the period of engine running and the amount of effort involved were being reduced, considering the respective characteristics of piston and turbine engines.

Did Mr. Lovesey consider that the form of type testing now called for was appropriate to the modern engine?

N. J. Hancock (Ministry of Supply, *Assoc. Fellow*): Had it been found possible to reproduce rumble at will on the test bed, and had its nature been established?

It had often been said that no engine was fit for use in civil aircraft until it was obsolete, and he would be interested to know what Mr. Lovesey thought about the development testing of a new type of engine together with a new type of aircraft. Was it not a good thing to put the two side by side and eliminate the troubles from both at one and the same time?

He thought everyone would be pleased to hear that Rolls-Royce Ltd. were taking a keen interest in axial engines particularly after all that had been heard on the matter a couple of years ago.

MR. LOVESEY'S REPLY

Air Commodore Banks: He agreed that flight testing technique should be extended and improved so that engine development would be less and less dependent on large and expensive altitude chambers. He thought that in time the measurement technique would have improved to the extent that the "flying test bed" would do all, and more, than the costly altitude chamber.

The testing of axial compressors under throttled conditions, to about one-third of the power required at full density had, in practice, not given rise to any measurable inaccuracies. Flight test data and compressor rig data was found to be in extremely close agreement.

Dr. Moult: To get the optimum results from Duple burners it was necessary to design them for a particular combustion system. The cone angle of the spray from both pilot and main burner was considerably modified by the degree of air swirl in a particular combustion system and the burners could be so proportioned that the flow from the main jet could be entrained and smoothly blended in with the pilot jet. In practice, excellent results had been obtained with Duple burners correctly matched to the combustion chamber design, and flight data taken between 40,000 ft. and 50,000 ft., over a wide range of engine speeds, had shown them to be greatly superior to other types of burners.

He agreed that the factor of safety on turbine blades depended both upon temperature and vibratory stresses and hot strain gauging in conjunction with temperature measurement was an attempt to obtain a fuller knowledge of the problem. At present strain gauges were confined to near the root of the blade and although there was not a large amount of test data available, the technique was being steadily improved. Design changes had been made but again, as yet, there was insufficient data to assess the value of the change.

The reason some residual stress was shown at the top of the blade was because of an error in the diagram. Actually the graph did not extend completely to the tip of the blade and the particular blades used in the test were fitted with shrouds.

The number of channels used was three.

Mr. Lawrence: Generally speaking, Mr. Lawrence's remarks about air entry conditions were in agreement with the paper, that the main requirement was to improve air conditions; then it was a much easier task to put things right afterwards.

He appreciated that the tests at Munich were done very rapidly; but they had to be done rapidly, for only a day or two afterwards the test plant had to be rooted out and taken away. When using a nice, shiny, chromium-plated plant such as that, one tended to "spread oneself." But they must keep the aim in view when conducting such tests; they could collect so many test results that

by the time they came to the third volume they had forgotten what they were looking for!

Dr. Jakobsson: The suggested decrease in effective nozzle area with aircraft speed was not supported by data so far obtained from flight calibration tests on a particular installation up to a Mach No. of 0.8.

If on a particular installation the contraction effect did occur it would be evident by an increase in jet pipe temperature, and the true effective nozzle area under those conditions could therefore be determined. This would then be allowed for in the calculation of thrust and there appeared to be no reason why thrust determined in flight by the methods described should not be accurate.

A contraction of 0.95 would mean an increase in jet pipe temperature of the order of 40 to 50°C., and changes of this magnitude would certainly not escape detection.

Dr. Morley: To obtain the net thrust the mass flow through the engine must be known. This was obtained from measurements of temperature and pressure conditions in the jet pipe and a knowledge of the effective nozzle area. The product of mass flow and aircraft velocity gave the momentum drag, which was subtracted from the gross thrust to obtain net thrust.

Mohamed Saeed: It was usual to explore the engine operation at low temperatures before going into production. Use was made of the facilities for such tests at the N.R.C. in Canada, whence valuable information was obtained on engine operation at very low temperatures. Coupled with that, low temperature starting was explored in the cold chamber plant.

Mr. Edwards: He did not wish to give the impression that it was only necessary to obtain uniform flow distribution round the flame tube to reduce tube buckling. It was even more important to obtain symmetrical conditions within the flame tube and this was difficult to accomplish with a non-uniform flow at the entry. With bad entry conditions to the flame tube the spray from the burner and the flame frequently became displaced to one side of the combustion chamber, which was the major cause of excessive distortion and cracking.

It was his experience that skin-cooled flame tubes alone would not overcome troubles arising from bad entry conditions, although they might afford some small improvement.

Some degree of flexibility in the flame tube construction at places of large temperature gradients was definitely beneficial.

He had found that fine atomisation was a very desirable factor, but the burner must be designed in careful relationship to the air flow reversal in the primary zone, so that the mixture well filled the flame tube.

With regard to instrumentation for thrust measurement in flight, he agreed there was always room for improvement. Temperature measurement by means of suction thermocouples could be, possibly, a little more accurate. The extremely close agreement of the results from flight measurements and those obtained in the Cleveland altitude chamber suggested there could be no appreciable error in either temperature or pressure measurements.

He agreed that measurements in very short jet pipes, such as the Vampire were extremely difficult.

Mr. Scott Hall: He considered there were possibilities of reducing the time, and consequently the expense, of developing engines. By fuller instrumentation of engines and maximum use of component rig testing many of the latent defects could be nipped in the bud before a lot of engine running had been done, which would avoid a repetition of work and an accumulation of obsolete and costly material. With increased knowledge there was every evidence that the gas turbine could be developed to a state of reliability sooner than the piston engine.

The British form of type test was excellent and far superior to that of any other country. Great credit was due to those who had steadily evolved the present schedule.

Mr. Hancock: Rumbling could be reproduced on the test bed. One source of the trouble was an unsuitable combination of pilot and main burners.

He agreed that it was a good thing to develop both a new type of engine and aircraft together. In parallel, a flying test bed was an extremely useful piece of equipment.

PROTOTYPE TESTING OF AIRCRAFT*

by

D. R. H. DICKINSON, A.F.R.Ae.S.

THE title of Prototype Testing is taken here to refer to the flight tests carried out on a new aircraft by its constructor. It embraces a wide field of subjects and in a short paper, it cannot be covered in any way comprehensively. I propose therefore to deal mainly with very general aspects of the subject.

The paper does not attempt to embrace out of the ordinary types with special problems peculiar to themselves—an extreme example of which is probably the Brabazon I. Most of my experience on this subject has been concerned with small aircraft, many of them single-seaters, and consequently some of my statements may apply more particularly to this type of aircraft, although many will probably apply equally to other types of aircraft.

1. PURPOSE OF TESTS

In general terms what does one aim at during the flight tests of a prototype and how does one set about the job?

The first important event is naturally the first flight and this it is hoped will prove, in an elementary way, the ability of the aircraft to be taken-off, flown around under reasonable control and then be brought back on to the ground (or water). With the present state of design knowledge it would be remarkable if the answers to these simple questions, without the qualifying queries that follow, were not answered satisfactorily. Nevertheless, the first flight is a definite milestone in the evolution of any particular aircraft.

The object of the tests that follow is, briefly, to make the aircraft satisfactory in every way in the shortest possible time—that is, to ensure that its handling qualities are safe and pleasant, that all its components and accessories function satisfactorily and that it meets the desired performance standards and any other requirements of the specification to which it was built. Moreover, these features are to be cleared under all possible conditions—between sea level and, say, 50,000 ft., during take-off and landing, in the air between the stalling speed and perhaps 700 m.p.h., when flying level, climbing, diving, turning, during aerobatics and possibly when spinning, and also under all possible loading conditions.

At the same time measured facts and figures are required to substantiate the results obtained, to satisfy potential customers and provide data for future designs. In addition it may be necessary to investigate such subsidiary matters as vibration, buffeting, noise, carriage of external armaments and fuel tanks and the jettisoning thereof, problems associated with operating from the deck of an aircraft carrier, or water handling problems for marine or amphibian aircraft. Some of these latter items alone may require much work and flying time to obtain satisfaction.

The actual features that require looking into on any aircraft will depend on the individual type, but some examples of the particular tests that may be required are shown in Table I.

The next point to be emphasised is that this work has to be accomplished in the shortest possible time. The necessity and value of saving time throughout the process of designing and producing a prototype is obvious, but in some ways it is of particular importance during the flight testing stage. The aircraft has been in the design and construction stages for two or three years and has now reached the state where it actually

*A Section Lecture given on 14th February 1950. This was the 792nd Lecture to be read before the Society.

Mr. Dickinson is head of the Technical Section dealing with Flight Testing at Vickers-Armstrongs (Supermarine) Ltd.

TABLE I

EXAMPLES OF FEATURES TO BE INVESTIGATED DURING PROTOTYPE TRIALS

I. *Handling*	II. *Performance*
Taxi-ing	Position error
Take-off and landing	Speed
Stalling	Climb
Longitudinal control	Take-off and landing runs
Lateral and directional control	Range, etc.
Limits of C.G. range	
Effects of flaps, dive brakes, etc.	
Asymmetric power tests	
Baulked landings	
High Mach number tests	
III. *Cooling*	IV. *External Stores*
Engine or coolant	Effects on handling
Oil	Effects on performance
Auxiliaries	Asymmetric loadings
	Jettisoning
V. *Comfort, etc.*	VI. *Functional*
C.O. contamination	Fuel system
Noise	Hydraulics
Heating and ventilating	Electrics
Vibrations	Pneumatics
Pressure cabin	

flies. Inevitably it becomes the focus of considerable interest which was previously relatively dormant; this interest and attention come both from departments within the firm and from the Ministry concerned and usually take the form of a demand for information of the aircraft's characteristics, capabilities and "saleability." A further point is that the flight testing is the last stage in the evolution of the prototype and the cumulative effect of all previous delays is felt, leading to a natural and urgent desire on the part of all concerned to make up for lost time. It is thus highly desirable that the flight tests should proceed as expeditiously as possible.

When actually setting about the tests, the first step is to find as early as possible those features which are in any way unsatisfactory, and the tests applied in the early stages should have this as their first objective. When a defect is found steps to have it put right should be taken at once, with the object of having the aircraft in its final form with all necessary alterations incorporated before the tests have gone too far. Apart from the obvious reason that the sooner the aircraft is right and in its final form the better it is from the maker's point of view, a great deal of time may be wasted and exasperation caused if a series of tests is done in some detail on an aircraft only to find that a subsequent alteration renders them, if not useless, at least inapplicable and having to be repeated.

The first stage is thus a fault-finding and fault-rectifying one, which will blend into the later stages of the tests which are in the main of a proving nature; that is, proving that the aircraft is in all ways safe and pleasant to fly and proving that it possesses the desired performance, and so on. It is during the proving stages that the main volume of quantitative data on the aircraft is obtained.

These fault-finding and proving stages are bound to overlap considerably since in some cases it is only by application of the proving tests that a fault is found. This leads to some of the most difficult tasks in the development testing stages, namely, to decide the order in which tests shall be made on a prototype, bearing in mind that the aim is to find any defective features, and also to decide how thoroughly any particular test shall be applied in the early stages. It is a waste of time to spend a lot of flying doing certain tests very thoroughly if the features tested are subsequently altered, yet the tests must be complete enough to ensure that the requirements of the test are met. The actual programme followed will evolve from, and be governed by, a combination of factors, such as a knowledge of the items in which the aircraft is theoretically "near the bone," the role the aircraft is designed for, the results obtained on early flights and, probably most important of all, the findings and opinions of the test pilots as the trials progress.

The development of a prototype obviously depends greatly upon the skill and judgment of the test pilot. The use of instruments and the making of quantitative tests, in the early stages, should be used to find the *cause* of a defect after its existence has been brought out by the pilot. One of the keys to rapid development of a prototype to its final form is the correct blending of the findings of pilots with the use of instrumentation. The pilot, normally, will be the quickest to indicate the *presence* of any undesirable feature, but quantitative measurements will most quickly show the *reasons* for its existence and indicate the probable cure. Instrumentation is also essential for the final proving stages where the characteristics of the aircraft are examined in detail and evidence of its behaviour accumulated.

Another type of testing which is more or less peculiar to prototype testing occurs when a defect has been found on the aircraft and has to be put right. An investigation is then often necessary which may involve special tests which do not come into the normal category of routine tests and cannot be classified. These may necessitate special preparations, varying from the installation of special types of instruments or instruments adapted to particular purposes, to the fitting and photographing of wool tufts.

Following this very general picture of the flight testing of a prototype, a few more detailed aspects of the process will be considered.

2. INSTRUMENTATION

To make the various tests necessary on a modern aircraft a large number of quantities have to be measured and recorded and the installation in the aircraft of the instruments required to do this is a matter that needs thought and attention long before the aircraft flies. Provision for the various instruments and recording apparatus with their mountings, wiring, and so on, must be made during the design of the prototype and built into the aircraft as it is constructed. On aircraft built for the Ministry of Supply a conference is held at an early stage at which details of the instrumentation required, its installation and the supply position, are discussed.

A comprehensive list of the quantities that have to be measured can only be compiled if one knows the particular aircraft to be tested and something about its operational role and characteristics. To give an idea of the scope of the measurements, Table II gives a list of some of the items that would probably need to be measured at any instant of flight during the tests of groups I, II and III of Table I.

It is not proposed to deal in detail with the types or characteristics of the various instruments used but there are a few more or less random points that might be mentioned in connection with Table II.

First, it will be noticed that measurements are required of the position of a number of moving parts on the airframe—elevators, ailerons, rudders, trimmer and spring tabs, flaps, gills, and so on. This can be done in various ways but the almost universal method at the present time is by use of the Desynn type of transmitter and indicator. This method is simple, reliable and of adequate accuracy for most purposes and has been of inestimable value in flight testing. As well as being used purely as a position indicator, the same type of transmission is used to transmit to the recording apparatus such items as control forces, angle of yaw, pressures and other quantities.

TABLE II

TO BE MEASURED DURING TESTS OF GROUPS I, II AND III OF TABLE I

All Groups

A.S.I., height, engine speed, boost, time, weight.
Positions of: Radiator flaps, cooling gills, landing flaps.

I. *Handling*

Positions of: Ailerons, elevator, rudder and attendant spring, balance or trimmer tabs.
Pilot's forces on: Aileron, elevator and rudder controls.
Angles of: Yaw, bank and pitch.
Rate of roll, normal acceleration.

II. *Performance*

Fuel flow, air temperature, differential air pressures (P.E. tests).
Torque (piston engines), thrust (jet engines).

III. *Cooling*

Temperatures and pressures at various points in the oil and coolant systems or cylinder temperatures. Rate of oil or coolant circulation. Cooling air flow. Cooling of and/or near compressor, generator, etc.

Aircraft weight can be ascertained at any moment from the readings of the fuel contents gauges, or more accurately and conveniently, from the readings of "gallons gone" type flow meters, which can be installed in an automatic observer.

Aileron and elevator control forces, up to now, have most commonly been measured using a one or two axis control force recorder with Desynn transmission. This method has proved reasonably satisfactory but involves either the replacement of the normal control handle by the transmitter unit which has a knob which the pilot grips, or superimposing this unit in some way on the control wheel. This has three possible disadvantages:—(1) the additional mass may alter the mass balance characteristics of the elevator circuit with consequent effects on longitudinal stability, etc.; (2) the fact that the pilot is not using the normal control grip prevents a full appreciation of the "feel" of the controls; and (3) in small cockpits the actual bulk of the unit may limit the travel of the stick. A preferable method of control force measurement from the viewpoint of the pilot and flight test technician is a force measuring

unit inserted at some convenient point in the circuit which may work either mechanically or might make use of strain gauges. Such units have been made and used but have disadvantages in the way of installation difficulties, at any rate in small aircraft.

Rate of roll can be obtained by a continuous record of angle of bank and time, or more conveniently by means of a rate of roll indicator, a gyro instrument which gives a direct indication of rate of roll.

Normal acceleration is measured either by the well-known Kollsman-type accelerometer or preferably by an instrument comprising a '*g*' sensitive transmitting unit situated near the centre of gravity of the aircraft with Desynn or other transmission to the indicator.

Various thermometers are available for the measurement of air temperature, of which the most frequently used is probably the Cambridge balanced bridge type because of its accuracy and small lag. This instrument, however, possesses the disadvantage that it cannot be installed in an automatic observer since the bridge has to be balanced manually and the temperature read visually. This is inconvenient, particularly in a single-seater aircraft, and in addition the instrument is relatively bulky for a small cockpit. It is understood that a self-balancing type instrument is being developed.

3. AUTOMATIC OBSERVATION

Consider now the methods of recording the readings of these instruments. Even in large aircraft where several human observers can be carried it is not practicable, except in certain specific tests, to record the information visually. Not only are the readings involved far too numerous but also for many of the tests continuous records, or at any rate readings at short regular intervals, are required to obtain satisfactorily the information desired.

Automatic observation is necessary therefore and the two most usual methods of achieving this are by using a camera to photograph a panel of instruments or by use of an apparatus whereby the values of several quantities are recorded as traces—either as light traces on a strip of film, or simply by a pen or scriber on paper.

The camera type has up to now been the most generally used. It is not proposed to discuss this piece of equipment in any detail but the main points to be considered in its design are to choose a camera (and lens) suitable to the number of instruments that are to be photographed, the space available and the type of records required (*i.e.* ciné or stills), to provide adequate lighting of the instruments, to avoid effects or vibration and to provide suitable means of control.

A still camera taking single pictures may be operated either directly by a switch or push button operated by the pilot or observer, by a type 35 control which can be set to operate the camera at pre-set time intervals variable from about 2 to 50 seconds, or by means of the impulse from the Kent-type flow meter that is usually fitted. The last mentioned method is used in conjunction with a "gallons gone" indicator and clock to measure fuel consumptions. It may be found that to operate the camera on every impulse from the flow meter would give more exposures than are required for the test being undertaken and would exhaust the film available too rapidly, in which case a device is incorporated whereby only every "n^{th}" impulse reaches the camera. Use of this method becomes a bit complicated on multi-engined aircraft where the fuel consumption of each individual engine is required, but is feasible if a means is provided of identifying which engine has caused any particular exposure to be taken.

Ciné cameras are usually simply controlled by a push button or switch which, in the interests of conserving film as well as for convenience, is preferably spring-loaded to the "off" position and situated on the control column in a single-seater aircraft.

Various types of camera are available for use in automatic observers; some, such as the F.24 and GSAP, are normally used for other purposes and have been adapted for this work while others such as the F.58 and F.73 have been developed especially for the purpose. The main disadvantage of most of the cameras available, from the flight tester's viewpoint, is that the film they carry is insufficient. Many flights, even on short duration aircraft, are terminated because the film has been exhausted. This prolongs the time required for a series of tests.

When any type of automatic observer is in use on a single-seater aircraft, or when it is not under the direct visual control of a human observer, it is desirable that the pilot be provided with some form of indication that the camera and lights are functioning correctly, in order to minimise the possibility of abortive flights.

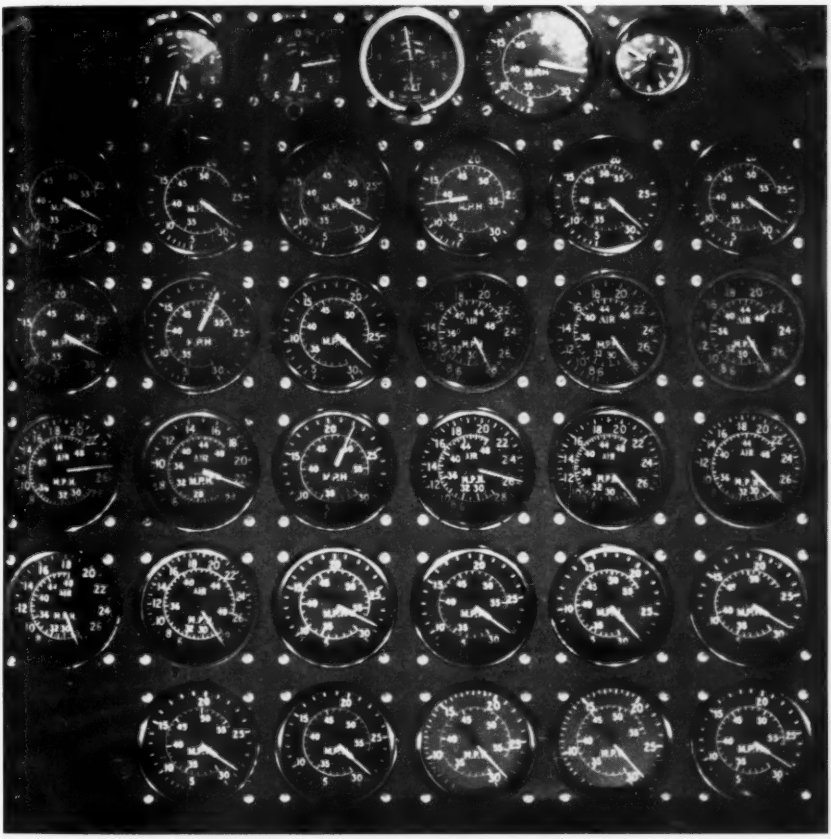


Fig. 1.
F.24 camera, 5 in. wide frames.

The use of the camera-type of automatic observer entails a considerable amount of work in the developing and reading of the films and analysis of the results, with a consequent time lag before the results are available, particularly if continuous ciné records are involved. This time lag can be kept surprisingly small by good team work and the provision of suitable film viewers, and so on.

For example, a fully used film from an automatic observer camera can be developed and dried ready for viewing within an hour of the aircraft landing; it can then be read by two people collaborating, in anything from one to three hours depending on the type of film and the type of test. The subsequent analysis and reduction process will take between 5 and 15 hours' work by one person which can be reduced by, say, two persons sharing the work intelligently.

The use of the other type of recorders where the quantities required are recorded continuously on a moving strip of film or paper, effect a considerable saving of time in analysis, as well as being convenient in other ways. Recorders of this type, in a form suitable for flight testing, have only recently been developed by Government establishments in Great Britain and are not yet available to the Industry in any quantity; no doubt some firms have developed and made their own apparatus on these lines. These recorders are particularly useful for all

tests where unsteady conditions are being measured, so long as they give the required degree of accuracy and are free from lag.

A few examples of the records obtained with various photographic observers are shown in Figs. 1-4. Figs. 1 and 2 were taken with an F.24 camera which produces frames about 5 in. square. Fig. 1 was obtained with an observer in the rear fuselage of a Spiteful aircraft and shows that quite a number of instruments can be photographed in a small space. The numerous air speed indicators were used in conjunction with a pitot rake behind the wing for profile drag measurements.

Figure 2 shows a typical panel used for performance and cooling tests on a Seafire 47 and is an example of good lighting and clarity. The Desynn indicators H-M recorded various pressures in the oil and coolant systems and also radiator flap position.

Figure 3 was taken with an F.58 camera which can take either ciné or still pictures using a 35 mm. film. It shows the observer used for quantitative handling tests on a single-engined amphibian aircraft. The gap in the bottom right hand corner was actually occupied by an instrument showing angle of bank for most of the tests. A row of indicator lights will be seen to the right of the panel which were used for recording events, as for example the raising of the undercarriage or the moment of touch-down during a landing.

Figure 4 is an enlargement from a 16 mm. ciné film and it is included for variety. The scratches were obtained during analysis of the film after developing. The observing instrument concerned was a hastily improvised one used for some rate of roll tests that were urgently required.

4. GENERAL REMARKS ON INSTRUMENTATION

On present-day aircraft comprehensive instrumentation of the prototype is essential and, far from being a waste of time, as has sometimes been suggested, it enables a great deal of time to be saved. In the pre-instrumentation days, faults found on a prototype were rectified largely by a combination of trial and error methods and intelligent guesswork and, for relatively low performance and simple aircraft, it was quite successful and satisfactory. On aircraft capable of performing at high speeds and

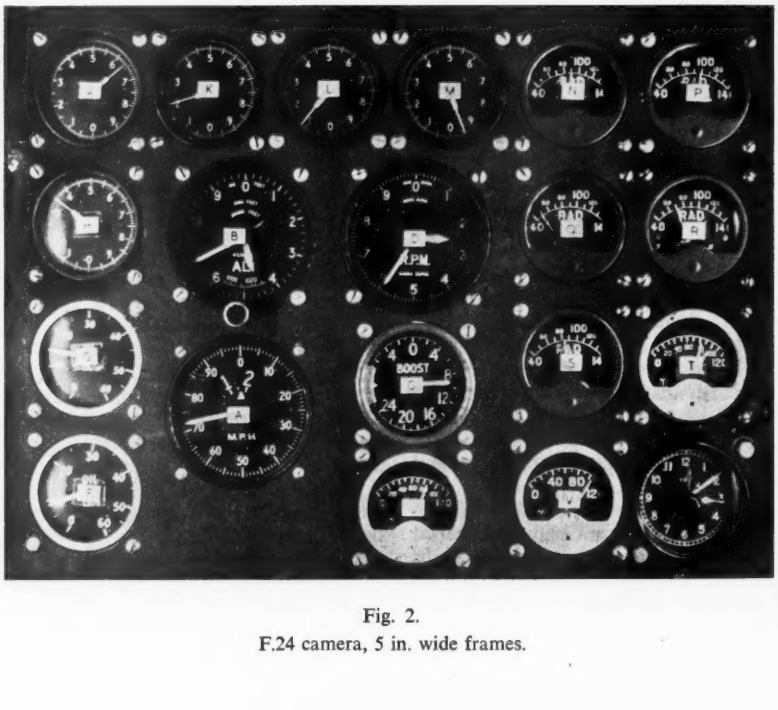


Fig. 2.
F.24 camera, 5 in. wide frames.

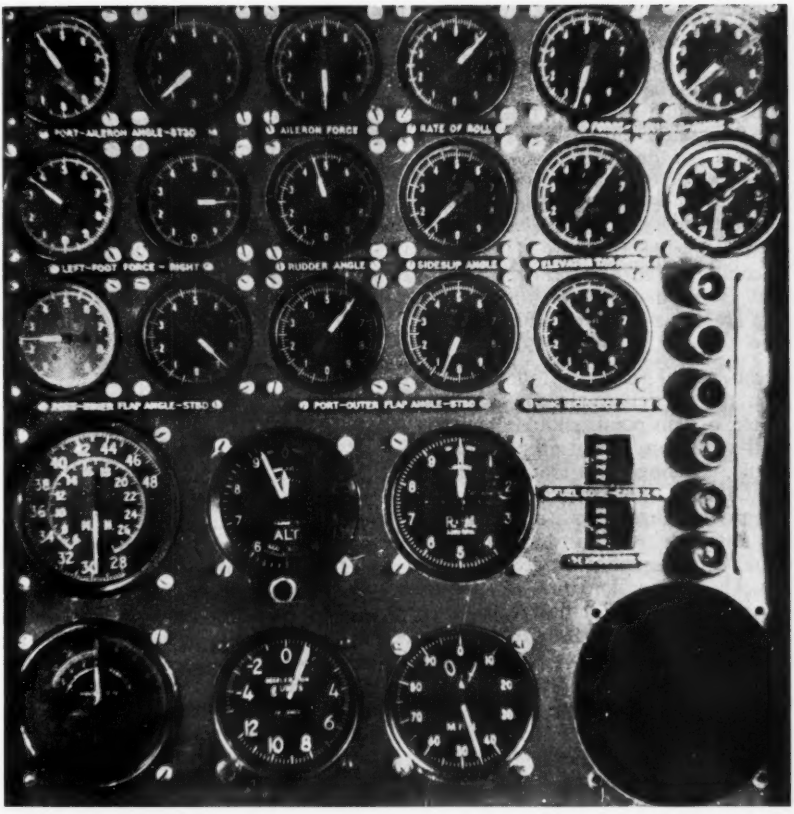


Fig. 3.
F 58 camera, Enlarged frame, 35 mm. film.

high altitudes (which mean high Mach numbers) as well as possessing such devices as, perhaps, power controls, dive brakes, pressure cabins, and so on, such methods cannot be applied. It is impossible to sort out effects that may occur as the results of, say, distortion of the control surfaces or compressibility, by any means other than actual measurements; even with the fairly thorough instrumentation now used it is usually possible to measure only a few of the quantities about which one would really like to know.

Another point is that with instrumentation much more information is obtained from a given amount of flying time, and the information so obtained can be analysed and used, not only to provide the answer required from the particular test made, but also to provide data for the benefit of the designers of subsequent aircraft.

I do not wish to give the impression of being in favour of measuring everything one can think of in case it turns out to be useful. This leads to needless expenditure of money and also of time unless a very large staff is available. Measurements should be confined to those quantities really necessary, but when they are made they should be thorough and accurate.

5. PLANNING

There should be some definite plan or schedule which gives a desirable order of

testing and ensuring that certain essential features are checked at an early date before the tests enter the stage when they become detailed. It will be almost impossible to stick to the schedule for many reasons—not always the fault of the aircraft. For example, special flights for demonstration purposes, flying displays and flights for photographic or other publicity reasons are liable to crop up frequently. These are very necessary events in assuring the future of the aircraft, but not conducive to the progress of the flight tests. Nevertheless, a plan is essential if the tests are to be executed efficiently and adequately.

While the actual schedule followed will depend on the particular aircraft, its type, size and role, certain points should obviously be checked on all aircraft at an early stage. For example, it is important that the aircraft be flown at the aft and forward limits of its centre of gravity range at an early stage; an alternative approach is to determine the forward and aft acceptable centre of gravity limits quickly. The longitudinal control characteristics (*i.e.* static stability and stick forces in manœuvres) are usually the primary factors in determining these limits and in applying the tests it is important to check an adequate number of conditions covering the full speed range, engine on and off, a height range, and such cases as the baulked landing. All conditions will be checked in due course but I am referring now to the preliminary handling tests, when the major objective is to find quickly any adverse features that require improving or rectifying.

During these preliminary tests the lateral and directional control characteristics should also be checked. At this stage simple tests in which the aircraft is displaced in yaw or roll and the ensuing motion observed qualitatively are probably adequate, together with straight side slips to check any rudder over-balance tendencies.

The stalling characteristics, flaps and undercarriage up and down will have been checked normally on the first flight, but will require some more thorough investigation at an early stage.

The normal routine of these flights at forward and aft centre of gravity positions should automatically check such features as changes of trim with power and flap, and also the functioning of the various electrical and hydraulic services and suchlike features.

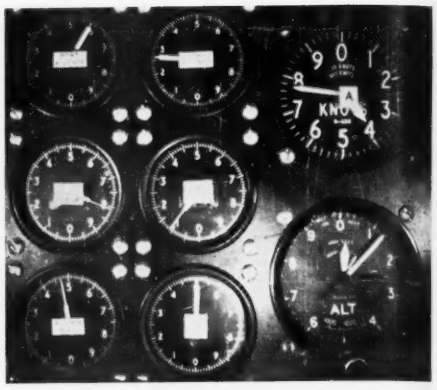


Fig. 4.
G.S.A.P. camera, enlarged frame, 16 mm. film.

On any particular aircraft no doubt there will be other features that are essential to check early in the trials, but brief preliminary tests of the nature just mentioned can be completed in quite a short time and should indicate any features that need attention. Any alterations to the aircraft should then be made before the main, more detailed, tests start.

Once the aircraft is in what is hoped will be its final form, the main proving tests will start in earnest, that is to say full performance measurements, cooling trials, full handling tests in which the quantitative data required is obtained and the various other tests that may be necessary.

Here again the time involved in making these tests can be kept to a minimum by carefully planning the tests, not merely in broad outline but in considerable detail. I think it is worth while to have a chart prepared for each set of tests (say a set of handling tests or a set of performance tests) listing the specific details of heights, engine conditions, speed, flap position and so on, for each individual test. This ensures that no condition is overlooked and can be used as a checking list as the tests proceed. It can also form the basis from which individual flight plans are built. Each flight should be planned to make the optimum use of the time in the air; as an elementary example, a test involving climbing to altitude should be followed by other tests at that altitude and, if possible, tests during the descent. Unsuitable weather tends to upset this sort of planning

but an alternative flight plan can usually be evolved to suit the conditions prevailing, and the pilot can be briefed with other tests to be done if weather interferes with the original tests laid down.

With aircraft that are fully instrumented it is often possible to combine two or more types of test, since very similar flight conditions are often required for tests of two different features. The most obvious example of this is the combination of cooling tests with performance tests on a piston-engined aircraft. As an example of this one might quote the case of a single-engined aircraft on which full cooling trials as called for in A.P.970 and full performance tests (which included partial climbs, normal and combat climbs, level speeds at combat and cruising powers and fuel consumption tests at two heights) were completed in 25 hours' flying. The period occupied by the tests was 12 days, on 9 of which the aircraft flew.

6. TESTING TIMES

It is difficult to give an indication of the period occupied by the tests since so much depends on what troubles are found during the preliminary tests and the magnitude of the work necessary to rectify them, and also on the type and size of the aircraft. For a fighter aircraft this preliminary period might occupy anything from about two months to getting on for a year. The time for the subsequent proving tests, that is handling tests on the lines of Chapter 9 of A.P.970, together with A.P.970 cooling tests, if required, and complete performance tests, again will depend on how much of these tests has already been done during the earlier tests, but will probably take two to four months.

The time taken for individual batches of tests, assuming the aircraft has arrived at its final condition, can perhaps be estimated a little more closely. Some examples for a typical fighter aircraft are given in Table III, the times being given in flying hours.

Figures of the nature shown in Table III are open to argument but those given are thought to be average figures, assuming the tests are done thoroughly but go fairly smoothly—they also assume that full instrumentation is available.

In case the details of the handling tests on Table III are not familiar, a brief summary of the measurements required, in addition to qualitative assessments, follows.

The take-off and landing tests involve obtaining continuous film records of control forces and movements during these manœuvres which are done at at least two centre of gravity positions and both into and across wind; also, records are obtained of the changes caused by movements of undercarriage and flaps.

The longitudinal control tests involve measurements of elevator and trimmer angles under a wide range of flight conditions to determine static stability, measurements of

TABLE III

EXAMPLES OF FLYING TIMES FOR VARIOUS TESTS. SINGLE-ENGINED FIGHTERS

Handling			
Tests to A.P. 970:			
Chapter 903 Take-off and initial climb Chapter 905 Approach and landing Chapter 912 Lateral and directional control, etc. Chapter 913 Longitudinal control, etc.		20-25 hours	
Chapter 908 High speed flight		2 hours	
Chapter 907 Flight at and near stall			
Performance and Cooling			
	JET		
0-40,000 ft.	Position error Partial climbs Climb (all practical engine conditions) Speeds (all engine conditions) Range and endurance (all conditions)	15-20 hours	
	PISTON ENGINE		
0-30,000 ft.	Position error Partial climbs Climb (2 engine conditions) Speed (2 engine conditions) Range, etc. (2 heights)	30 hours	35-40 hours
	Engine Cooling (A.P. 970 tests) Oil cooling (A.P. 970 tests)	15 hours	

stick forces to recover from trimmed dives and in out-of-trim dives and other tests, all again at at least two centre of gravity positions.

Lateral and directional tests involve automatic observer records of aircraft and control behaviour following displacements in yaw, of control movements and forces in sideslips, rate of roll tests and others.

Under performance, jet and piston-engined aircraft are considered separately. Piston-engined fighters are now becoming obsolete but the figures will also apply to other fairly small military aircraft. In the piston-engine column are included cooling trials and some idea is given of the time saved by combining the performance and cooling tests.

It will be noticed that the time to measure performance fully on the jet aircraft is appreciably the lesser and furthermore, a more complete set of data is available when the tests are complete than on the piston-engined type.

7. METHODS

It is not proposed to discuss in any detail the actual methods and techniques used for the various tests since the methods are fairly well known and moreover were given comprehensively in the lecture delivered to the Society by E. T. Jones, in 1944*.

The testing methods given in that lecture are generally still current practice. The main development during the intervening years has been the advent of turbine-engined aircraft, which were not specifically dealt with by the lecturer, and a few general remarks on testing these aircraft follow.

The testing methods for jet aircraft are basically similar to those for piston-engined aircraft, but there are certain new problems and changes in technique and also, certain simplifications.

A major reduction in work is that engine cooling trials as done on piston-engined aircraft are almost entirely eliminated. A certain number of temperature measurements are usually necessary but on nothing like the same scale. The cooling of accessories still has to be checked.

The outstanding feature of jet aircraft is their performance and, at present, steady flight at high subsonic speeds is readily achieved. Since they are capable of reaching high Mach numbers easily, their handling characteristics under such conditions must be thoroughly explored. Jet-engined prototypes therefore must be tested at Mach numbers which a few years ago were unobtainable, or only attainable in a steep dive at high altitude. The behaviour under these conditions is made easier and safer to investigate by the very fact that they can be reached in level flight, or only a shallow dive. In recent years a fair amount of experience has been obtained and knowledge gained of the behaviour of aircraft at high Mach numbers by both firms and experimental establishments. But the way any particular aircraft will react as Mach number is increased is still, to some extent, unpredictable and the first exploratory tests towards high Mach numbers on a prototype must be conducted with considerable caution. That is to say, the usual precautions of making the tests as high as possible and increasing Mach number very gradually are followed and any phenomena observed are examined carefully before proceeding further. Instrumentation to record the changes with Mach number of control surface angles, control forces, and other quantities is essential for these tests.

The high speeds obtainable, as well as introducing compressibility effects, also make aeroelastic effects more pronounced and the analysis of these effects and separating them from pure compressibility effects, again necessitates adequate instrumentation and a fair amount of flying.

The technique for performance testing of jets differs in some respects from that used for piston engines because of the different reduction methods employed. It is not proposed to describe these methods here but in the most commonly used method, measurements are made so as to enable a series of curves or carpets to be plotted from which the performance of the aircraft under any stipulated conditions can readily be deduced. As already indicated, a set of these curves to cover comprehensively climb, speed and range characteristics, can be obtained on a typical single-engined jet fighter in about 15 hours' flying, provided that the aircraft is fully instrumented. At the end of this time far more information is available about the performance of the aircraft than could be obtained from the same amount of flying on a piston-engined aircraft. If by any chance a quick performance (say speed) check is required and only one or two hours' flying can be spent on it, one will not get a lot of reliable information with a jet aircraft,

*JONES, E. T. Flight Testing Methods. JOURNAL R.Ae.S., May 1944.

although one may get something worth while from a piston-engined type. However by spending 10 or more hours' flying on the job, far more information will be obtained from tests on the jet.

An advantage with jet aircraft is that by placing a pressure head in the jet pipe it is possible to measure the thrust being produced, or at any rate get a value very near it. This, in conjunction with the performance tests, enables the drag of the aircraft to be readily obtained—a valuable piece of information to the design staff, particularly when high Mach number conditions are involved.

8. FUNCTIONING TESTS

When the subject of flight testing is mentioned one tends to think of performance, handling, and suchlike tests, but an important aspect of the tests, particularly on prototype aircraft, is checking the functioning of such things as the hydraulic, electrical and pneumatic systems, with which one might couple fuel transfer systems and possibly, pressure cabin installations, de-misting devices, and so on.

A good deal of the testing of these services is done on the ground before any flights are made, but it is often necessary to make tests under flight conditions to check such features as, for example, the temperatures and pressures in the hydraulic system, the temperature of electrical equipment or the functioning of fuel transfer systems under various conditions of flight.

9. TESTS BY EXPERIMENTAL ESTABLISHMENTS

In the case of most aircraft, and certainly of aircraft built for the Ministry of Supply, the usual procedure is for the contractor to do all the initial trials on the prototype and prove that its behaviour is satisfactory, that it meets specification requirements and is in all ways airworthy. The aircraft is then handed over to the A. & A.E.E. or M.A.E.E. whose duty it is to subject the aircraft to acceptance tests and prove its suitability and acceptability to the ultimate user—*i.e.* one of the services or the appropriate civil aircraft organisation.

The testing establishments naturally have a somewhat different approach towards the tests to that of the firm testing their own prototype aircraft. Nevertheless a large part of the technique and application of the tests will be identical to that already carried out by the firm and many of the tests will virtually be repeats to verify the firm's results.

This duplication of the tests is, to some extent, necessary if the testing establishment is to ensure that the desired standards of aircraft behaviour and performance are met, but at the same time the testing process of modern aircraft tends to take an undesirably long time and a procedure involving duplication of tests is clearly uneconomic from a time saving viewpoint. With the increasing use of instrumentation, whereby automatic observer records of tests are obtained which subsequently can be examined and individually analysed by the testing establishment, as well as the firm, the case for eliminating some of the duplication of tests is increased. In consequence, discussions on this point have recently taken place between the Industry and the Ministry of Supply and agreement has been reached on a scheme whereby a certain amount of the results of the firm's tests on the aircraft are accepted by the testing establishment. In practice, firms will be approved for flight testing by the Ministry in a similar manner to the existing scheme for design approval. When a firm has obtained flight testing approval the testing establishment will accept most of their quantitative results, with probably a few spot checks, and will confine their work mainly to qualitative tests.

This scheme will lead to an appreciable reduction in the testing period of new aircraft.

10. ORGANISATION

The arrangements for dealing with the organising and technical control of the flight testing probably varies from firm to firm, but one really essential point is that those responsible for this work should be housed at the aerodrome in close contact with the aircraft being tested and the test pilots. The necessity for very close collaboration with the test pilots cannot be over-emphasised; the test pilots and technicians should not regard themselves as two bodies in liaison with each other but as parts of one team. It is preferable that there should be a separate technical unit of the design staff dealing with the flight testing. It must maintain close liaison with the various other units of the design staff, not only while the flight tests of the prototype are in progress but for some time before the tests start.

A portion of the flight testing organisation will be the section dealing with instrumentation. The work of this section has increased considerably in recent years and includes the provision, calibration, installation and maintenance of the instruments, and design, construction and installation of automatic observers which involve cameras, controls, lighting and so on. Workshop, laboratory and dark room facilities are required for this work. Since instrumentation of the prototype starts during the design stages and is incorporated in the aircraft as it is built, the instrument personnel are concerned with the job from a very early stage.

The main technical section deals with such matters as planning the flight programme, briefing pilots, analysing and correcting results, preparation of technical reports, and a number of related matters. One point, which may appear small but is particularly important, especially on prototype tests, is to ensure that an accurate log or diary of the tests is kept, with particular reference to the condition of the aircraft at any time, making sure that all changes made are accurately recorded. This ensures, among other things, that account is kept of changes in loading or affecting the loading; in this connection if the flight test section itself does not carry out weighings and deal with loading matters, a close working liaison must be established with the weights section.

11. FINAL REMARKS

In this paper some idea of what is involved in the testing of a prototype has been expressed. It should perhaps be pointed out that the aircraft spends by far the greater part of its time on the ground, no matter how well the flying programme goes. It is kept on the ground for maintenance purposes, for periodic inspections, to incorporate alterations found necessary as the result of flight tests, because of unsuitable weather, and at night.

Modern radio aids enable test flying to continue in weather conditions that would otherwise rule it out, but it is really only aircraft with fairly long endurance that can make appreciable use of this. It is not of much help to the short endurance jet-fighter type of aircraft. Radio can also be used with advantage during certain types of flight tests; for example, it is not uncommon now for the pilot to give a commentary during spinning trials which are received and possibly recorded on the ground. One can visualise other ways in which radio and allied devices could be employed in flight testing, but regular use of these is not yet current practice. It is, however, desirable that we should keep our testing technique flexible and be prepared to modify it or adapt it to take full advantage of any developments or suggestions that will increase the efficiency and expediency with which it is executed.

ERNST MACH - Pioneer of Supersonics

by

JOSEPH BLACK, M.Sc., A.F.R.Ae.S.

IT IS a curious reflection on the progress of science in our time, that a term which has only come into common use in aeronautics in the last decade commemorates the name of a man who carried out his researches some fifteen years before the Wright Brothers first flew in 1903. The obscurity surrounding Ernst Mach, whose name is given to the ratio of the speed of flow of a gas to the speed of sound under the same conditions, is ill-deserved, for there can be little doubt that he was one of the outstanding scientific personalities of the nineteeth century; this distinction arises not so much from his experimental work, which was extremely valuable, but more from his original conceptions on the philosophy of science which helped to lay the foundation for modern developments in physics. Aeronautical engineers are naturally more interested in the former aspect of his career, and examination of his papers on the subject of projectiles and shock waves, some details of which follow, shows that he merits the perpetuation of his name in this field. Since it has fallen to their lot to preserve Mach's memory, it is appropriate that they should also have some appreciation of his life and other work.

Ernst Mach was born on the 18th February 1838 at Turas in Moravia, which is now part of Czechoslovakia. He studied at the University of Vienna and in 1864 became Professor of Mathematics at Graz, which he left in 1867 to become Professor of Physics at Prague. In 1895 he returned to Vienna as Professor of Physics, but subsequently he changed his chair to that of the "Theory of the Inductive Sciences." He retired from this position in 1901, and shortly before the First World War he left Vienna and went to live in a lonely house near Munich until his death on the 19th February 1916. During the latter part of his time at Vienna he had had a serious stroke which paralysed him, and he depended on visitors for his contact with the scientific world outside.

In spite of his birthplace, one may surmise that Mach was Germanic in outlook. When he was "Rector Magnificus" of Prague University in 1879 he fought against the introduction of the Czech language into the University to replace German, which was then the official language. This must be seen against the background which then existed; Prague at that time was only one of the cities of the Austro-Hungarian Empire, which was ruled from Vienna, and the demand for the recognition of Czech as the official language was a step in the direction of autonomy for the States which eventually, after the First World War, grouped together to form Czechoslovakia. He was made a Member of the Austrian House of Peers in 1901, and as already mentioned, spent his retirement in Germany.

SUPERSONIC INVESTIGATIONS

Mach communicated the results of all his experiments on the flight of projectiles and flow of gas jets to the *Transactions* of the Academy of Science of Vienna (Sitz d. Akad. d. Wien). His most outstanding paper, upon which the term "Mach Angle" is based, appeared in Volume 21 in April 1887, under the title "Photography of Projectile Phenomena in Air," a joint paper with Salcher, a Professor in the Marine Academy in Fiume, where the experiments described in the paper were carried out with the co-operation of the Royal Austrian Navy. Salcher, incidentally, was the joint author of a paper in the same Transactions with another notable person; this was the Englishman, John Whitehead, also of Fiume, the inventor of the torpedo.

Paper received May 1950.

Mr. Black is Lecturer in Aeronautical Engineering, University of Bristol.

PROFESSOR ERNST MACH (1838-1916).

Shells were fired at varying muzzle velocities past the metal plates of a condenser connected to a charged Leyden jar, the shell automatically taking a Schlieren photograph of itself by causing the discharge of an electric spark. About eighty photographs with knife edges both vertical and horizontal were taken. Fig. 1 shows two of these photographs reproduced from the original paper, and considering the quality of the photographic materials then available, they are a remarkable achievement.

After commenting on the waves in the photographs Mach, as a basis for their analysis, discusses the propagation of sound waves from the end of an infinitely thin rod moving through a fluid. In Fig. 2 may be seen his triangle about which he says, "The . . . waves will have as an envelope a cone, . . . If we call the angle mab α, the velocity of sound v, speed of advance ω, then $v/\omega =$ sine α. For $\omega = v$ sine α becomes 1. The extremity of the rod touches all elemental waves which it produces on its way. If ω is less than v, the equation loses its geometrical sense . . . The appearance of sharp density

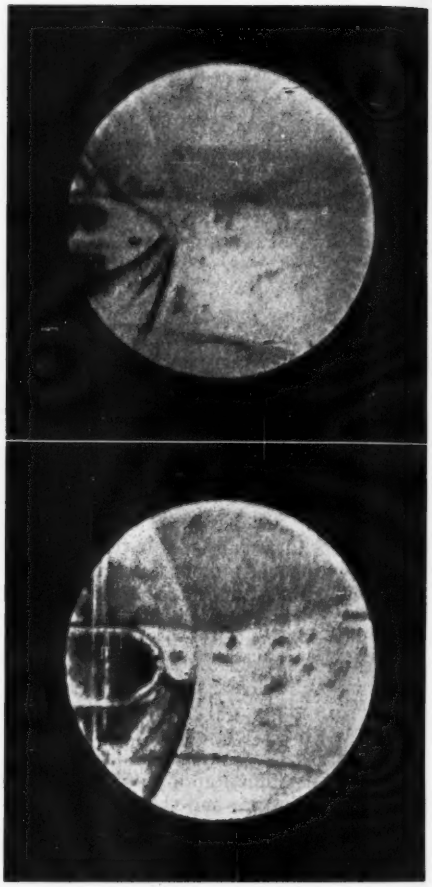


Fig. 1.

Schlieren photographs of shock waves ahead of projectile nose obtained by Mach (1881).

borders is governed by the condition $\omega \lesseqgtr v$. For $\omega > v$, from sine α we obtain the relation of the velocity of sound to that of the body."

Mach realised, however, that the nose waves in the photographs were, in fact, shock waves and not sound waves, for he goes on to explain that a finite body will produce a finite, and at large velocities, a considerable compression wave in front, and that the propagation speed of this wave will be greater than that of sound. "The compression in front of a projectile at supersonic speed has to become so great, . . . until its propagation velocity

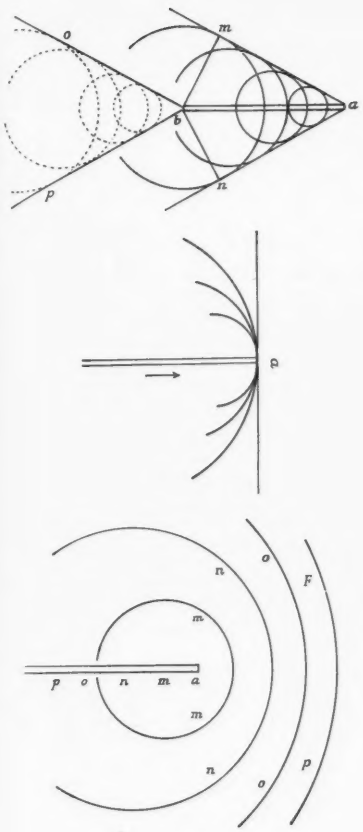


Fig. 2.

Mach's illustrations of sound wave propagation in subsonic and supersonic flows.

equals that of the projectile . . . Following the nose wave backwards, the angle α of the element relative to the line of flight must fall off slowly and approach the limiting value $\sin^{-1} \omega/v$ . . . the curve is thus comparable to a hyperbola . . . The vertex of the wave, therefore, lies nearer the nose for higher velocities . . . Pointing of the projectiles also brings the wave vertex nearer the nose."

Among further equally valuable discussion, a comment is made on the resemblance of the shock wave formation to that produced by a ship in water, or in water flow past a bridge pier. "It is possible to reproduce this phenomenon if we take a rod of cross-section *AB* in a large water tank and move it at a velocity which exceeds the velocity of wave propagation." This is all the more remarkable in view of the interest being taken at present in the so-called Hydraulic Analogy, usually ascribed to Riabouchinsky since he developed the appropriate quantitative relations in a paper published in 1932.

What is equally far-seeing, is Mach's suggestion, towards the end of the paper, that an analytical treatment of the flow past the projectile would have to be based on a successive approximation method, and that an experimental approach to this might be made by using "a silver-coated copper sheet on the bottom of a container with an electrolyte and non-conducting model projectile and dipping metal probes connected to batteries to find the equipotentials (Nobili-Guebhard)." In actual fact this suggestion was not acted on, so far as the writer is aware, until 1928 when Taylor and Sharman[1] used it for investigating the field of flow of a compressible fluid past a cylinder.

The association of Mach's name with the wave angle α did not follow until some twenty years later, when Meyer and Prandtl used the term "Mach Angle" in their papers in 1907/8. The term "Mach number" was first used by Ackeret in 1929, although he did not use it in his article on Gas Dynamics in the *Geiger-Scheel Handbuch de Physik* published in 1927; incidentally, Ackeret did point out in this article that the explicit relationship for the angle goes back to Doppler (1847). Even Busemann, in his contribution on Gas Dynamics to the *Wiens-Harm Handbuch der Physik* in 1931 only uses the term once, and there credits it to Ackeret. Later it was used on several occasions at the Volta High Speed Conference in Rome in 1935[2]. The first appearance of Mach's name in this connection in English was in the translation of Prandtl's book in 1930[3], but nevertheless it was not used by Taylor and Maccoll in their contribution on compressible flow to the volumes of *Aerodynamic Theory* (Durand) in 1933. It was only when used by Maccoll in his paper of 1937 that the terms became established in English. By 1939/40 they were coming into general use, and at the National Physical Laboratory the term "Mach number" replaced the "specific speed" which had been in use there since Stanton's early work[4].

In passing, it is interesting to note that while the terms are in general use in most parts of the world, the Russians often use the

term "Bairstow number." A possible explanation for their refusal to acknowledge Mach may lie in Lenin's objections to the Machian philosophy, as mentioned later. The Soviet physicist Joffre, however, stated in 1925 that Lenin had only attacked the philosophical followers of Mach, and not Mach's scientific achievements, which he had recognised as outstanding.

A recent French paper[5] claims that Mach's name should not be associated with the term, since a French General Moisson is reputed to have written a paper in 1842 on the importance of the ratio of the velocity of a projectile to that of sound. The author, therefore, suggests that the term should be renamed the "Moisson number."

OTHER PAPERS AND BOOKS

Other allied papers were published by Mach in 1889, one of which, "Optical Examination of Air Jets," included what must be the first Schlieren photographs of a supersonic air jet emerging from an orifice (Fig. 3). There are also some papers written in collaboration with his son, Ludwig. The last paper by Ernst Mach in these "Transactions" is one on a theory of the wave phenomenon of falling meteors. All the subsequent papers are by his son. This fact is probably little known, because the credit for the development of the optical system with which the density of a flowing gas may be measured, known as the Mach-Zender interferometer, is usually given to Ernst Mach, when actually it was Ludwig who wrote the paper on it. In this paper, "On an Interferencerefractometer" (1893), he acknowledges the help of his father, and it is true that Ernst does deal with such systems in his text books on optics.

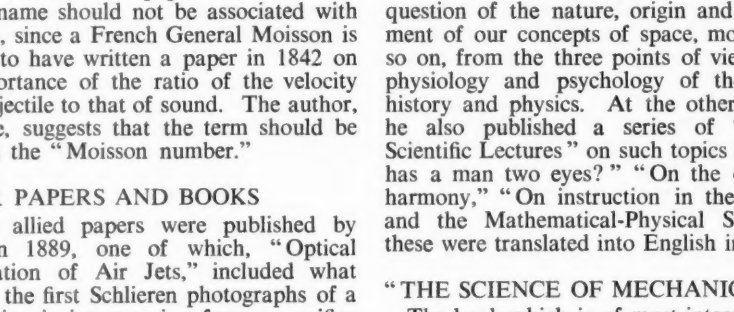


Fig. 3.
Mach's photograph of a supersonic air jet (1889).

Ernst Mach also wrote a considerable number of books, mainly on physics for students, optics and thermodynamics, but there are others which are a little more difficult to classify. These have titles which are rather unusual, such as "Theory of the Sensation of Motion" (1875), "Analysis of the Sensations" (1886) and "Perception and Error" (1905).

In these latter books, Mach discusses the question of the nature, origin and development of our concepts of space, motion, and so on, from the three points of view of the physiology and psychology of the senses, history and physics. At the other extreme he also published a series of "Popular Scientific Lectures" on such topics as "Why has a man two eyes?" "On the causes of harmony," "On instruction in the Classics and the Mathematical-Physical Sciences"; these were translated into English in 1895.

"THE SCIENCE OF MECHANICS"

The book which is of most interest to the engineer and physicist is "Die Mechanik in ihrer Entwickelung" published in 1883 and translated into English in 1902 as "The Science of Mechanics." It was not intended as a treatise upon the application of the principles of mechanics: "Its aim is to clear up ideas, expose the real significance of the matter, and get rid of metaphysical obscurities."

A facet of Mach's personality is revealed later in the introduction: "In this immediate connection with the text stand the facsimile reproductions of old originals in my possession. The quaint and naive traits of the great inquirers, which show in their expression, have always exerted upon me a refreshing influence in my studies, and I have

desired that my readers should share this pleasure with me."

His statement on the importance of an historical study of a scientific subject is as apt today as when he wrote it: "They that know the entire course of the development of science will, as a matter of course, judge more freely and more correctly of the significance of any present scientific movement than they, who limited in their views to the age in which their own lives have been spent, contemplate merely the momentary trend that the course of intellectual events takes at the present moment."

Starting from the earliest ideas on Mechanics, Mach examines in great detail the growth of the various conceptions which have succeeded each other through the ages. It is with Dynamics, however, that Mach is really concerned, and he devotes considerable attention to Galileo's achievements and influence. This leads him next to Huygens, whom Mach clearly regarded as of equal stature to Galileo, and indeed, he justifies this view by discussing Huygens' contributions to the theory of the centre of oscillation, the determination of the acceleration of gravity, and other topics.

Since the main thesis of the book is Mach's criticism of Newton's concepts, he examines Newton's writings at some length, to the extent of much direct quotation. After praising the profound intellectual and imaginative advances made by Newton, Mach explains in detail why some of Newton's concepts should be reformulated. For example, Newton's definition of mass as "quantity of matter" he dismisses, and suggests that it be replaced with "all those bodies have equal mass, which mutually acting on each other, produce on each other equal and opposite accelerations." This definition thus makes Newton's statement on the Law of Reaction superfluous, which accorded with Mach's emphasis on the need for "economy of thought." By this he meant that the greatest possible number of observable facts should be covered by a minimum number of principles. This economic nature of scientific theory he compared to the economy of practical life.

In Mach's opinion, Newton's laws were not products of the imagination, since none of the principles involved was self-evident They represented, rather, a summary by Newton of all the conditions covering his observations of motion. Consequently, if conditions remained identical to those of Newton's experience, then his laws could be used for the prediction of the movement of any individual body. When these conditions are altered, the predictions based upon Newton's Mechanics must perforce be inapplicable.

Mach also disagreed with Newton's use of expressions which could not be related to any experimental observation. Thus, such expressions as "absolute space" and "absolute time," he considered meaningless. They should be eliminated, and only propositions from which deductions about observable phenomena can be deduced should be used. Mach proposed instead that the motion of bodies should only be considered relative to the fixed stars. Thus in Foucault's pendulum experiment, it will be seen that the pendulum maintains its plane of oscillation relative to the fixed stars, and not to "absolute space."

The importance of this more exact Law of Inertia—"every body maintains its velocity, both in magnitude and direction, relative to the fixed stars as long as no forces act upon it"—is that it indicates that the fixed stars may exert an additional influence on a moving body independent of gravity. This influence is hardly measurable with the motion of bodies on the earth, but might be appreciable, so far as Mach knew, in the Universe.

Lest it be thought that Mach had any pretentions to being another Newton, his justification for daring to attack such an eminent figure should be remembered. (Chapter 2, Section 7, English Edition.) "Upon the whole, we may say that Newton discerned in an admirable manner the concepts and principles that were sufficiently assured to allow of being further built upon. It is possible that to some extent he was forced by the difficulty and novelty of his subject, in the minds of the contemporary world, to great amplitude, and therefore, to a certain disconnectedness of presentation, in consequence of which one and the same property of mechanical processes appears several times formulated. To some extent, however, he was, as it is possible to prove, not perfectly clear himself concerning the import and especially concerning the source of his principles. This cannot, however, obscure in the slightest his intellectual greatness. He that has to acquire a new point of view naturally cannot possess it so securely

from the beginning as they that receive it unlaboriously from him. He has done enough if he has discovered truths on which future generations can further build. For every new inference therefrom affords at once a new insight, a new control, an extension of our prospect, and a clarification of our field of view. Like the commander of an army, a great discoverer cannot stop to institute petty inquiries regarding the right by which he holds each post of vantage he has won. The magnitude of the problem to be solved leaves no time for this. But at a later period, the case is different. Newton might well have expected of the two centuries to follow that they should further examine and confirm the foundations of his work, and that, when times of greater scientific tranquillity should come, the principles of the subject might acquire an even higher philosophical interest than all that is deducible from them. Then problems arise like those just treated of, to the solution of which, perhaps, a small contribution has here been made. We join with the eminent physicists Thomson and Tait, in our reverence and admiration of Newton. But we can only comprehend with difficulty their opinion that the Newtonian doctrines still remain the best and the most philosophical foundation of the science that can be given."

Mach is not quite so lenient with Descartes. After a long quotation from Descartes' "Principia Philosophiae" (1644), Mach observed that Descartes was inflicted with all the usual errors of the philosopher. "He places absolute confidence in his own ideas. He never troubles himself to put them to experimental test. On the contrary, a minimum of experience always suffices him for a maximum of inference." One wonders what Mach's reaction would be today on finding that many chapters in philosophical text books are devoted to "Mach, the Philosopher," while he only warrants a few lines in histories of science.

The remainder of the book deals with the extension of Newton's principles, and there are many sections of particular interest, as, for example, the pedigree of such terms as "momentum," "impulse," "kinetic energy and work," which we use today, often without appreciating the breadth of vision and imagination which has gone into their conception. Another section deals with the theory of dimensions, so universally employed in aeronautics; in this Mach suggested that every new expression in mechanics should be investigated by this means.

MACH'S INFLUENCE

Mach's outlook on these fundamental considerations led to two important related trends in science and philosophy. In physics it affected Einstein. As Frank[6] says, "Some of Hume's ideas also appear in the writings of Ernst Mach, the leader of central European positivism. Next to Hume, Mach was the philosopher who exerted the greatest influence on Einstein. Mach's criticism that such expressions as 'absolute space,' 'absolute time,' and 'absolute motion' could not be connected in any way with physical observations was one of the points from which Einstein set out to replace Newton's theory of motion by his own. 'Mach's postulate' has in many instances been a useful point of departure for new theories. According to this 'postulate,' for every physical phenomenon the conditions of its occurrence must be sought among other observable phenomena. Later, 'Mach's postulate' led Einstein to advance his new theory of gravitation," and again[7], "This new theory of Einstein was a fulfilment of the programme of Ernst Mach. From the material bodies present in space it enables one to calculate the curvature of space, and from this the motion of bodies. According to Einstein, the inertia of bodies is not due, as Newton has assumed, to their efforts to maintain their direction of motion in absolute space, but rather to the influence of the masses about them—the fixed stars, as Mach had suggested."

From the philosophical viewpoint, Mach's postulates gave rise to the movement known as "positivism," which suggested that general laws were only summaries of observations. Later, this gave way to the conception that laws are creations of the imagination which are only tested by observations; this is distinguished as "logical positivism." When fully developed, the Machian philosophy tended to an idealist outlook which could even deny the existence of an external world, and made science a subjective instead of an objective subject. This provoked Lenin to make a strong attack on the Machians in his book "Materialism and Empirio—Criticism."

This brief glance at Mach's work should suffice, it is hoped, to establish the statement made in the introduction that Mach was an outstanding scientific personality. Inevitably, much of his writing was obscure, dealing as it did with topics on the borderline of science, but that is hardly a justification for his neglect. It is an odd twist of fate that his name is perpetuated in connection with work which Mach himself would probably have dismissed as his most trivial, but from our point of view we can indeed honour him as a true pioneer of supersonics.

References

1. Taylor, G. I. and Sharman, L. On a Mechanical Method for Solving Problems of Flow in Compressible Fluids. R. & M. 1195, 1196, 1928.
2. MacColl, Dr. J. W., Correspondence with
3. Ewald, Pöschl and Prandtl. *Physics of Solids and Fluids.* Blackie, First Edition, 1930.
4. Fage, A., Correspondence with
5. Gabeaud, M. L. Le Nombre de Moisson. *Memorial de L'Artillerie Française,* Vol. 21, No. 82, 1947.
6. Frank, Philipp. *Einstein, His Life and Times.* Jonathan Cape, 1949, pp. 68-69.
7. *Loc. cit.,* pp. 163-164.

THE ROYAL AERONAUTICAL SOCIETY
WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

EIGHTY-FIFTH ANNUAL REPORT OF THE COUNCIL 1949–1950

A SUMMARY of the Society's activities for January-December 1949 was given in the January 1950 JOURNAL.

On the 17th of January 1949 the Charter of Incorporation was signed and the Royal Aeronautical Society became a Body Corporate. The main By-Laws of the Society have been approved by the Privy Council and will shortly be printed and sent to all members.

The granting of the Charter of Incorporation was marked by the founding of a Royal Aeronautical Society Charter Scholarship to the value of £300 a year to assist a student wishing to undertake advanced work or study in aeronautics. The first award of the Charter Scholarship was made to John Anthony Dunsby, B.Sc., in September 1949 to enable him to take a Post-Graduate Course in Aeronautics at the Imperial College of Science and Technology, London.

In the summary of activities in the January 1950 JOURNAL an account was given of the proceedings of the Second International Aeronautical Conference held in New York in May 1949. Active preparations are now going ahead for the Third Conference, which will be held in London in September 1951. Many members who took part in the first Conference in London in 1947 will remember with lively interest the visit of the American delegates and it is hoped that the 1951 Conference will see the renewal of many friendships.

During the year the Council sponsored the publication by the Society of *The Aeronautical Quarterly*, the first issue of which appeared in May 1949. Founded to enable papers describing new and original work, or papers reviewing progress in some specialised field of activity to be published, *The Aeronautical Quarterly* has received considerable support but its success must depend on the continuance of that support.

In October 1949 the first of the Section or Specialist Lectures was read. These lectures, begun to enable highly specialised aspects of aeronautical engineering and science to be discussed, have proved so successful that they are being continued.

There has again been a satisfactory increase in the membership of the Society. For the first time in the summary of Membership, there appears as separate items the membership details of the Australian, New Zealand and South African Divisions which were formed in 1948. From reports received by the Council there is little doubt that the formation of these Divisions will add greatly to the influence of the Society. It is hoped in due course to publish the annual reports of the Councils of the Divisions. (The first, the Annual Report of the New Zealand Division for 1949, was published in the May 1950 JOURNAL.)

The Council for the year 1949-50 was as follows:—

COUNCIL 1949-50

PRESIDENT

SIR JOHN S. BUCHANAN, C.B.E. (*Fellow*)

PAST PRESIDENTS

H. ROXBEE COX, Ph.D., D.I.C. (*Fellow*)
SIR FREDERICK HANDLEY PAGE, C.B.E. (*Hon. Fellow*)

VICE-PRESIDENTS

W. G. A. PERRING, C.B. (*Fellow*)
N. E. ROWE, C.B.E., B.Sc., D.I.C. (*Fellow*)
H. C. WATTS, M.B.E., D.Sc. (*Fellow*)

ORDINARY MEMBERS

E. J. N. Archbold (*Associate Fellow*) (Died May 1949)
Lord Brabazon of Tara, M.C. (*Hon. Fellow*)
Major G. P. Bulman, C.B.E., B.Sc. (*Fellow*)
S. Camm, C.B.E. (*Fellow*)
A. V. Cleaver (*Associate*)
G. P. Douglas, O.B.E., M.C., D.Sc., (*Fellow*)
G. R. Edwards, M.B.E., B.Sc. (*Fellow*)
A. G. Elliott, C.B.E. (*Fellow*)
W. S. Farren, C.B., M.B.E., M.A., F.R.S. (*Fellow*)
Sir A. H. Roy Fedden, M.B.E., D.Sc. (*Fellow*)
Sir Arthur Gouge, B.Sc. (*Fellow*)
Major F. B. Halford, C.B.E. (*Fellow*)
Professor A. A. Hall, M.A. (*Fellow*)
S. Scott Hall, C.B., M.Sc., D.I.C. (*Fellow*)
J. W. F. Housego (*Graduate*)
P. G. Masefield, M.A. (*Fellow*)
W. Tye, O.B.E., B.Sc. (*Fellow*)
C. F. Uwins, A.F.C., O.B.E. (*Fellow*)

OFFICERS

Honorary Treasurer: C. F. Uwins, A.F.C., O.B.E. (*Fellow*)
Honorary Librarian: J. E. Hodgson (*Hon. Fellow*)
Solicitor: L. A. Wingfield, M.C., D.F.C. (*Associate*)
Secretary: Captain J. Laurence Pritchard (*Hon. Fellow*)

COMMITTEES OF COUNCIL

Grading Committee
Dr. H. C. Watts (Chairman)
Mr. S. Scott Hall
Mr. A. C. Clinton
Professor A. A. Hall
Mr. S. Camm
Mr. G. R. Edwards
Mr. W. Tye
Dr. E. S. Moult
Mr. H. Sammons

Education and Examinations Committee
Professor A. A. Hall (Chairman)
Dr. G. P. Douglas
Mr. W. Tye
A/Cdre. A. H. Robson
Mr. M. Langley
Mr. D. J. Farrar
Dr. E. S. Moult
Mr. E. F. Relf

Medals and Awards Committee
Mr. W. G. A. Perring (Chairman)
Mr. S. Scott Hall
Professor A. A. Hall
Mr. N. E. Rowe
Mr. S. Camm
Major F. B. Halford
Sir Arthur Gouge
Mr. W. S. Farren

Editorial Board
Mr. W. G. A. Perring (Chairman)
Dr. H. Roxbee Cox
Mr. G. H. Dowty
Professor S. Goldstein
Mr. J. Smith
Sir Richard Southwell

Journal Committee
Mr. G. H. Dowty (Chairman)
Mr. P. G. Masefield
A/Cdre F. R. Banks
W/Cdr. C. G. Burge
Mr. L. Bridgman
Major R. H. Mayo
Mr. W. S. Farren

Graduates and Students Committee
Mr. J. W. F. Housego (Chairman)
Mr. P. T. Fink
Mr. M. C. Campion
Mr. M. K. Bowden
Mr. J. C. Gibbings
Mr. S. Scott Hall
Mr. A. V. Cleaver
Mr. J. G. Roxburgh
Mr. A. Stanbrook

Technical Committee
Mr. W. G. A. Perring (Chairman)
Mr. E. L. Bass
Mr. I. Bowen
Mr. H. L. Cox
Mr. H. Davies
Sir A. H. Roy Fedden
Mr. H. H. Gardner
Professor A. A. Hall
Professor A. G. Pugsley
Mr. N. E. Rowe
Mr. J. Smith
Mr. R. S. Stafford
Mr. H. F. Vessey

Branches Committee
Mr. N. E. Rowe (Chairman)
Mr. A. C. Clinton
Mr. A. V. Cleaver
Mr. P. G. Masefield
Mr. E. J. Mann
Mr. S. A. Clark
Mr. D. B. Smith
Mr. J. L. Batchelor
Mr. E. J. Richards

General Purposes Committee
Dr. H. C. Watts (Chairman)
Mr. C. F. Uwins
Mr. N. E. Rowe
Sir A. H. Roy Fedden
Sir Frederick Handley Page
Mr. W. G. A. Perring
Dr. H. Roxbee Cox
Sir Arthur Gouge
Sir John Buchanan

Lectures Committee

Major G. P. BULMAN (Chairman)
Mr. N. E. ROWE
Mr. S. SCOTT HALL
Mr. M. B. MORGAN
Mr. J. W. F. HOUSEGO
Mr. A. V. CLEAVER
Mr. P. G. MASEFIELD
Mr. D. L. HOLLIS-WILLIAMS
Mr. J. SMITH

Finance Committee

Mr. C. F. UWINS (Chairman)
Mr. G. H. DOWTY
Major G. P. BULMAN
Dr. H. ROXBEE COX
Mr. W. G. A. PERRING
Dr. H. C. WATTS
Sir ARTHUR GOUGE

REPRESENTATIVES ON OTHER BODIES

General Board of the National Physical Laboratory: Sir Frederick Handley Page and Sir Arthur Gouge.

Royal Society—Scientific Information Conference: Professor A. A. Hall.

Royal Society—National Committee: Professor A. A. Hall.

Royal Society—International Union of Theoretical and Applied Mechanics: Professor A. A. Hall.

Royal Society of Arts—Conference on the proposed 1951 Exhibition: Sir Frederick Handley Page.

Institution of Electrical Engineers—Committee on Regulations for the Electrical Equipment of Aircraft: Mr. C. G. A. Woodford.

Institution of Electrical Engineers—Committee on Radio Equipment for Civil Aircraft: Mr. C. H. Jackson.

Institution of Mechanical Engineers—National Certificates and Diplomas in Mechanical Engineering: Professor F. T. Hill and Sir Frederick Handley Page.

Engineering Joint Council—Sir John S. Buchanan and Dr. H. C. Watts.

Engineering Joint Council—Special Education Representative: Professor G. T. R. Hill.

Governing Body of Loughborough College—Mr. A. G. Elliott.

Board of Governors of the R.A.E. Technical College—Mr. W. S. Farren.

College of Aeronautics: Sir Roy Fedden and Dr. H. Roxbee Cox.

British Gliding Association: Mr. G. H. Lee.

British Standards Institution—Nomenclature Committee: Dr. D. M. A. Leggett.

British Standards Institution—Aircraft Committee: Sir Roy Fedden and Sir Arthur Gouge.

British Standards Institution—Jewels and Pivots for Instruments Committee: Major B. W. Shilson.

British Standards Institution—Technical Committee M/1: Mr. S. Camm.

Segrave Trophy Committee: Major R. H. Mayo.

City & Guilds of London Institute—Advisory Committee on Aeronautical Engineering Practice: Mr. K. T. Spencer, Sir Roy Fedden, Professor R. L. Lickley and Capt. J. L. Pritchard.

Association of Special Libraries and Information Bureaux: Mr. J. E. Hodgson (Honorary Librarian).

National Central Library: Mr. J. E. Hodgson (Honorary Librarian).

University of London—Faculty of Engineering Special Committee: Mr. W. G. A. Perring and Mr. R. S. Stafford.

Regional Advisory Committee for Mechanical Engineering: Sir John S. Buchanan.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Society, held on Thursday, 5th May 1949 was reported in the JOURNAL for January 1950. At this meeting the list of Fellowship elections for 1949 was announced.

MEMBERSHIP

The following table shows the state of the Membership:—

MEMBERSHIP AT 31st DECEMBER 1949

Grade	London Register	Australian Division	New Zealand Division	Southern Africa Division	Life and Honorary	Totals	Suspended Members (included in foregoing figures)
Fellows ...	353 (357)	10 (11)	2 (1)	1 (—)	44 (39)	410 (408)	5 (5)
Associate Fellows	2498 (2273)	63 (52)	28 (15)	41 (41)	10 (11)	2640 (2392)	62 (66)
Associates ...	2064 (2096)	64 (55)	45 (32)	85 (80)	4 (6)	2262 (2279)	186 (173)
Graduates ...	1110 (836)	17 (14)	3 (1)	2 (4)	— (—)	1132 (855)	28 (31)
Students ...	860 (1064)	46 (41)	— (1)	3 (4)	— (—)	909 (1110)	97 (89)
Founder Members	17 (17)	— (—)	— (—)	— (—)	1 (1)	18 (18)	2 (2)
Companions	189 (215)	2 (2)	2 (1)	3 (4)	6 (9)	202 (231)	14 (33)
Temporary Hon. Members	— (—)	— (—)	— (—)	— (—)	37 (34)	37 (34)	— (—)
	7091 (6858)	202 (185)	80 (51)	135 (133)	102 (100)	7610 (7327)	394 (399)

Figures in brackets are those for December 1948

ELECTION OF PRESIDENT AND VICE-PRESIDENTS

Sir John S. Buchanan, Vice-President, was elected President of the Society for the year 1949-50 at the Council Meeting on 31st March 1949, and took office at the meeting on 12th May 1949.

The following were elected Vice-Presidents of the Society for the year 1949-50 at the Meeting of the Council held on 12th May 1949:—

W. G. A. Perring, Esq., C.B., F.R.Ae.S.
N. E. Rowe, Esq., C.B.E., B.Sc., D.I.C., F.R.Ae.S.
Dr. H. C. Watts, M.B.E., M.Inst.C.E., F.R.Ae.S.

TECHNICAL WORK

During the year the work on the data sheets, monographs and other technical activities of the Society was continued. The number of data sheets now issued is of the order of 250. These sheets cover Structures, Aerodynamics, Performance and Fuels and Oils, the last in co-operation with the Institute of Petroleum.

The value of these sheets is evidenced by the increasing demand for them from aircraft firms, government establishments and individuals both in Great Britain and abroad. Close on a thousand sets of these sheets have now been sold.

The Council wish particularly to draw attention of the members of the Society to the fact that the publication of those sheets would not have been possible on their present scale by the Society without the generous and ready co-operation of the Ministry of Supply and the Society of British Aircraft Constructors. The Ministry of Supply and the Society of British Aircraft Constructors bear equally between them a considerable part of the heavy expenses involved and the Council take this opportunity of expressing their grateful appreciation of the assistance given to the Society in this way. The Council also wish to place on record a gift of £300 a year for seven years which has been made by Sir George Nelson towards the cost of the Society's Data Sheets.

The Council through the Technical Committee and Sub-Committees have also during the year sponsored the publication of monographs. The first, "The Properties of Metallic Materials at Low Temperatures" by Major P. L. Teed, has now been published, and the second, "The Physical Structure of Metals in Relation to their Properties" by Dr. P. Chalmers, is in the press. Arrangements have been made for the publication of a further twenty monographs on Materials, Instruments, Hydraulics, Aeroelasticity, Performance and Aerodynamics. Further monographs are under consideration and the Council wish to thank the Committees, as well as the authors, for the work they are doing to help in providing much needed summaries of the state of the art in various aspects of Aeronautical technology.

The Council particularly wish to place on record their appreciation of the work of the Technical Staff during the year. The value of the data sheets and their accuracy depend very largely on the work of the staff and the Society has been very fortunate in those who have worked for it.

BRANCHES

In the January 1950 JOURNAL a list of Branch lectures and activities for 1949 was given.

The Third Main Society Lecture to be given at a Branch was held at Bristol when Mr. E. J. Richards, M.A., B.Sc., A.F.R.Ae.S., lectured on "Review of Aerodynamic Cleanness" on 24th November 1949. The President of the Society, Sir John S. Buchanan, was in the chair.

GRADUATES' AND STUDENTS' SECTION

A report of the Section's activities was published in the JOURNAL for January 1950.

FINANCE

The Income and Expenditure Accounts and Balance Sheets of the Royal Aeronautical Society and Aeronautical Trusts Ltd. for 1949 are published with this Report.

OFFICERS AND COMMITTEES

The Council wish to place on record their appreciation of the work which has been done by the Honorary Officers of the Society during the year.

Mr. C. F. Uwins, F.R.Ae.S., the Honorary Treasurer, has given invaluable advice and help in financial matters.

Mr. J. E. Hodgson, Honorary Librarian for so many years, has again during the year 1949 continued to advise the Society on all matters pertaining to the Library.

The Council wish particularly to place on record their appreciation of the work of the various Committees. Much of the work being done by certain of the Committees has involved many meetings during the year and the results which they have achieved will prove of great value to the Society.

STAFF

The Council wish to place on record their appreciation of the work of the staff of the Society during the past year. It is hardly necessary to say that the efficient conduct of affairs depends almost exclusively on their efforts.

The Society is fortunate in having available the services of an energetic and loyal staff filled with enthusiasm for the advancement of its interests.

HONOURS

A list of those Members who received Honours during 1949 was published in the JOURNAL for January 1950.

ACKNOWLEDGMENTS

A list of acknowledgments was published in the January 1950 JOURNAL.

HONORARY FELLOWSHIPS AND MEDALS AND AWARDS

A full list was published in the January 1950 JOURNAL.

OBITUARIES

The Council regret the death of the following members during the year:—

H. Adams (*Associate*)
M. J. G. Ash (*Student*)
D. L. Berry (*Student*)
J. C. de Heodt (*Associate*)
J. W. Dunne (*Fellow*)
F/Lt. S. E. Esler (*Associate*)
E. J. Kirby (*Associate*)
Dr. A. Klemin (*Companion*)
S/Ldr. K. A. Major (*Associate*)
L. Malabbott (*Associate*)
F/Lt. J. S. R. Muller-Rowland (*Companion*)
F. H. Ordidge (*Associate Fellow*) (Australian Division)
C. E. R. Osman (*Fellow*)
Miss W. E. Penn-Gaskell (*Companion*)
E. L. Pickles (*Fellow*)
G. F. Rayner (*Companion*)
W. M. Reichsfeld (*Associate Fellow*)
J. A. H. Sargeaunt (*Associate Fellow*)
F/Lt. D. Selvey (*Associate Fellow*)
Mrs. Walker Sinclair (*Companion*)
Lt.-Col. S. Heckstall Smith (*Fellow*)
A. Sutcliffe (*Associate*)
M. S. W. Templeman (*Associate Fellow*)
C. D. Tong (*Associate Fellow*)
S/Ldr. D. D. Weightman (*Associate*)

Balance Sheet

	£ s. d.	£ s. d.	£ s. d.
Current Liabilities—			
Sundry Creditors		5161 15 11	
Amount due to Aeronautical Trusts Ltd., Royal Aeronautical Society Endowment Fund		452 17 3	
Subscriptions and other amounts received in advance		2225 6 0	7839 19 2
Surplus—			
Publications Development Account—			
Amount transferred from Aerial Science Ltd. (being balance at credit at 31st December 1948)		6187 19 4	
Deduct—			
Expenditure on AERONAUTICAL QUARTERLY during year *less* sales to date	954 5 0		
Cost of printing "Aeronautical Conference London 1947" *less* amounts received ...	436 1 0	1390 6 0	
		4797 13 4	
Income and Expenditure Account—			
Amount transferred from Aerial Science Ltd. (being surplus at 31st December 1948) ...	9082 15 9		
Add Share Capital of Aerial Science Ltd. repaid	19 0		
	9083 14 9		
Less Excess of Expenditure over Income for year to date	4560 1 5	4523 13 4	9321 6 8
			£17161 5 10

J. S. BUCHANAN, *President.*
C. F. UWINS, *Honorary Treasurer.*

REPORT OF THE AUDITORS TO THE MEMBERS

In our opinion and to the best of our information and according to the explanations given to us the above Balance Sheet and Income and Expenditure Account are properly drawn up so as to exhibit a true and correct view of the state of the Aeronautical Society Endowment Fund included in the annexed accounts of Aeronautical Trusts Ltd., give a true and correct view of the state of the affairs of the Company as at 31st December 1948, and of its income and expenditure for the year ended on that date. We have obtained all the information and explanations which to the best of our knowledge and belief were necessary for the purposes of our audit. In our opinion proper books of account have been kept by the Company so far as appears from our examination of those books, and the accounts are in agreement therewith.

3 Frederick's Place, Old Jewry, London, E.C.2.
16*th March* 1950.

Income and Expenditure Account

1948 Figures Aerial Science Limited £ s. d.		£ s. d.	£ s. d.
	To Establishment Expenses—		
1330 17 10	Ground Rent, Heating, Lighting, Insurance and Repairs		2472 3 3
	„ Office and Staff Expenses—		
6960 8 10	Salaries	6895 18 4	
336 19 10	Staff Pensions Premiums	295 4 7	
1512 16 1	Printing and Stationery	1545 7 11	
1042 12 9	Postages and Telephone	1267 2 9	
266 18 6	Office Equipment	111 15 0	
1530 19 5	Other Charges	1141 16 3	11257 4 10
11650 15 5			
	„ JOURNAL and Sundry Publications—		
13057 3 3	Printing Costs	16134 10 9	
1020 6 2	Postages	1713 10 8	
2652 18 2	Other Charges	1986 11 8	
16730 7 7		19834 13 1	
3904 13 4	*Less*—Sales 4266 16 7		
8920 15 0	Advertisement Revenue ... 8614 0 0	12880 16 7	6953 16 6
3904 19 3			
2594 19 11	„ Expenditure on Data Sheets, *less* amounts recoverable		3754 4 10
541 18 3	„ Meetings		431 17 8
— — —	„ Anglo-American Conference 1949		2032 8 5
— — —	„ Garden Party		117 12 11
689 4 5	„ Dinners and Receptions		410 11 11
2890 18 9	„ Library Expenses		971 17 8
228 9 6	„ Branch Expenses		308 6 6
125 14 10	„ Prizes and Donations		90 15 7
— — —	„ Charter Scholarship		100 0 0
191 6 9	„ Legal and Professional Charges		368 2 0
— — —	„ Cost of Charter		466 15 9
870 10 5	(Surplus)		
£25019 15 4			£29735 17 10

AERONAUTICAL SOCIETY

BY ROYAL CHARTER 1949)

31st December 1949

	£ s. d.	£ s. d.
Current Assets—		
Investments at cost ... ... (Market Value 31st December 1949, £7,723)	7801 4 2	
Stock of Journals and other publications ...	1 0 0	
Sundry Debtors	4295 10 10	
Payments in Advance	219 1 1	
Cash at Bank and in Hand	4793 8 9	17110 4 10
Investment in Aeronautical Trusts Ltd.—		
21 shares of 1s. each fully paid at cost		1 1 0
Printed Books, Bindings, Old Prints, etc.—		
At nominal amount		50 0 0
		£17161 5 10

OF THE ROYAL AERONAUTICAL SOCIETY

balance sheet and the annexed income and expenditure account of the Society together with the accounts of the Royal fair view of the state of the Society's affairs as at 31st December 1949 and of its deficit for the year ended on that date. necessary for our audit. In our opinion the Society has kept proper books of account and the above mentioned

(*Signed*) PRICE, WATERHOUSE & CO.

for the Year ended 31st December 1949

1948 Figures Aerial Science Limited £ s. d.		£ s. d	£ s. d.
19974 16 0	By Annual Subscriptions		21326 1 2
574 10 0	„ Donations		428 9 6
122 14 6	„ Interest on Investments (Gross)	89 3 9	
57 0 2	„ Interest on Investments (*less* Tax)	75 9 2	
3797 3 1	„ Interest on Endowment Fund Investments (*less* expenses)	2982 15 5	3147 8 4
80 15 3 (Income Tax recovered)			
4057 13 0			
	„ Examinations—		
939 16 0	Fees received	1200 4 0	
526 19 8	*Less*—Expenses	926 6 7	273 17 5
412 16 4			
— — —	„ Balance, being Excess of Expenditure over Income for year, carried to Balance Sheet ...		4560 1 5
£25019 15 4			£29735 17 10

Balance Sheet

1948 Figures								
£	s.	d.		£	s.	d.	£	s. d.
			Share Capital—					
			Authorised—40 Shares of 1s. each				2 0 0	
1	1	0	*Issued*—21 Shares of 1s. each fully paid					1 1 0
			Royal Aeronautical Society Endowment Fund—					
129304	9	5	*Capital Account*—Balance at 31st December 1948 ..				130699 13 5	
17	8	0	*Add*—Donations received during year				11 11 0	
1377	16	0	Entrance Fees received during year				1243 4 0	
130699	13	5					131954 8 5	
5799	17	3	*Income Account*—Accumulated Surplus at 31st December 1948				5799 17 3	137754 5 8
136499	10	8						
			Pilcher Memorial Fund—					
99	14	0	*Capital Account*—As at 31st December 1948				99 14 0	
63	12	4	*Income Account*—Balance at 31st December 1948 ..	68	19	8		
5	7	4	*Add*—Income for year to date	5	7	4	74 7 0	174 1 0
168	13	8						
			Usborne Memorial Fund—					
109	2	5	*Capital Account*—As at 31st December 1948				109 2 5	
74	14	0	*Income Account*—Balance at 31st December 1948 ..	80	13	4		
			Add—Surplus of Income over Expenditure for year to					
5	19	4	date		19	4	81 12 8	190 15 1
189	15	9						
			Herbert Akroyd Stuart Fund—					
691	9	0	*Capital Account*—As at 31st December 1948				691 9 0	
489	1	5	*Income Account*—Balance at 31st December 1948 ..	527	8	7		
			Add—Surplus of Income over Expenditure for year to					
38	7	2	date	16	11	10	544 0 5	1235 9 5
1218	17	7						
			R.38 Memorial Fund—					
981	13	10	*Capital Account*—As at 31st December 1948				981 13 10	
776	7	5	*Income Account*—Balance at 31st December 1948 ..	810	2	10		
33	15	5	*Add*—Income for year to date	58	19	2	869 2 0	1850 15 10
1791	16	8						
			Edward Busk Memorial Fund—					
449	6	1	*Capital Account*—As at 31st December 1948				449 6 1	
218	18	10	*Income Account*—Balance at 31st December 1948 ..	223	4	11		
			Less—Excess of Expenditure over Income for year to					
4	6	1	date		7	8	222 17 3	672 3 4
(Surplus)								
672	11	0						
			Wilbur Wright Memorial Fund—					
2136	17	11	*Capital Account*—As at 31st December 1948				2136 17 11	
194	10	4	*Income Account*—Balance at 31st December 1948 ..	207	14	2		
			Add—Surplus of Income over Expenditure for year to					
13	3	10	date	5	18	4	213 12 6	2350 10 5
2344	12	1						
			Simms Gold Medal Fund—					
527	15	9	*Capital Account*—As at 31st December 1948				527 15 9	
37	14	9	*Income Account*—Balance at 31st December 1948 ..	48	2	11		
10	8	2	*Add*—Income for year to date	16	7	4	64 10 3	592 6 0
575	18	8						
			Alston Memorial Fund—					
245	6	0	*Capital Account*—As at 31st December 1948				245 6 0	
53	8	1	*Income Account*—Balance at 31st December 1948 ..	65	14	5		
			Add—Surplus of Income over Expenditure for year to					
12	6	4	date	3	18	2	69 12 7	314 18 7
311	0	5						
			Geoffrey de Havilland Memorial Fund—					
4175	17	5	*Capital Account*—As at 31st December 1948				4175 17 5	
—	—	—	*Income Account*—Balance at 31st December 1948 ..	66	14	6		
66	14	6	*Add*—Income for year to date	66	14	6	133 9 0	4309 6 5
4242	11	11						
£148016	9	5						£149445 12 9

J. S. BUCHANAN, *President.*

C. F. UWINS, *Honorary Treasurer.*

REPORT OF THE AUDITORS TO THE

In our opinion and to the best of our information and according to the explanations given to us the above Company's affairs and of the Funds administered by it as at 31st December 1949 and of the surplus and deficit of the We have obtained all the information and explanations which to the best of our knowledge and belief were accounts, which are in agreement therewith, give in the prescribed manner the information required by the Companies

3 Frederick's Place, Old Jewry, London, E.C.2.
16*th March* 1950.

TRUSTS LIMITED

31st December 1949

1948 Figures								
£ s. d.		£ s. d.	£ s. d.	£ s. d.				
1 1 0	*Cash in Hand*						1 1 0	
	Royal Aeronautical Society Endowment Fund—							
	Leasehold Property at cost—*Less* amounts written off							
12120 16 6	4, 8 and 9 Hamilton Place, at cost	12120 16 6						
4845 16 6	*Less*—Amortisation written off to date	5330 16 6		6790 0 0				
7275 0 0								
	Furniture at cost—*Less* depreciation—							
4570 5 0	At cost	4570 5 0						
2030 13 3	*Less*—Depreciation written off to date	2259 5 0		2311 0 0				
2539 11 9								
125602 16 9	Investments at cost (Market Value 31st December 1949 £119,636, including £1,000 2½% Defence Bonds (unquoted) at cost.)			127942 16 9				
3583 7 6	Cash at Bank			257 11 8				
180 15 6	Amount due from Royal Aeronautical Society			452 17 3		137754 5 8		
(Income Tax refund)								
139181 11 6								
2682 0 10	(Amount due to Aerial Science Limited)							
136499 10 8								
	Pilcher Memorial Fund—							
156 5 0	Investments at cost (Market Value 31st December 1949, £142)			156 5 0				
12 8 8	Cash at Bank			17 16 0		174 1 0		
168 13 8								
	Usborne Memorial Fund—							
174 11 1	Investment at cost (Market Value 31st December 1949, £158)			174 11 1				
15 4 8	Cash at Bank			16 4 0		190 15 1		
189 15 9								
	Herbert Akroyd Stuart Fund—							
1102 15 8	Investment at cost (Market Value 31st December 1949, £994)			1102 15 8				
116 1 11	Cash at Bank			132 13 9		1235 9 5		
1218 17 7								
	R.38 Memorial Fund—							
1754 6 2	Investment at cost (Market Value 31st December 1949, £1,558)			1754 6 2				
37 10 6	Cash at Bank			96 9 8		1850 15 10		
1791 16 8								
	Edward Busk Memorial Fund—							
658 8 8	Investments at cost (Market Value 31st December 1949, £679)			658 8 8				
14 2 4	Cash at Bank			13 14 8		672 3 4		
672 11 0								
	Wilbur Wright Memorial Fund—							
2250 14 9	Investments at cost (Market Value 31st December 1949, £2,353)			2250 14 9				
93 17 4	Cash at Bank			99 15 8		2350 10 5		
2344 12 1								
	Simms Gold Medal Fund—							
504 12 0	Investments at cost (Market Value 31st December 1949, £468)			504 12 0				
71 6 8	Cash at Bank			87 14 0		592 6 0		
575 18 8								
	Alston Memorial Fund—							
290 0 0	Investments at cost (Market Value 31st December 1949, £297)			290 0 0				
21 0 5	Cash at Bank			24 18 7		314 18 7		
311 0 5								
	Geoffrey de Havilland Memorial Fund—							
4175 17 5	Investment at cost (Market Value 31st December 1949, £3,842)			4175 17 5				
66 14 6	Cash at Bank			133 9 0		4309 6 5		
4242 11 11								
£148016 9 5						£149445 12 9		

MEMBERS OF AERONAUTICAL TRUSTS LTD.

balance sheet and the annexed income and expenditure accounts give a true and fair view of the state of the Funds for the year ended on that date.
necessary for our audit. In our opinion the company has kept proper books of account and the above mentioned Act, 1948.

(*Signed*) PRICE, WATERHOUSE & CO.

Income and Expenditure Accounts
Royal Aeronautical Society

1948 Figures				1949 Figures		
£	s.	d.		£	s.	d.
485	0	0	To Amortisation of Leasehold Property	485	0	0
213	15	0	„ Depreciation of Furniture	228	11	9
3797	3	1	„ Surplus of Income over Expenditure for year transferred to Royal Aeronautical Society	2982	15	5
£4495	18	1		£3696	7	2

Pilcher

5	7	4	To Income for year carried to Balance Sheet	5	7	4
£5	7	4		£5	7	4

Usborne

—	—	—	To 1949 Award	5	0	0
5 (Income)	19	4	„ Surplus of Income over Expenditure for year carried to Balance Sheet		19	4
£5	19	4		£5	19	4

Herbert Akroyd

—	—	—	To 1949 Award	21	0	0
38 (Income)	7	2	„ Surplus of Income over Expenditure for year carried to Balance Sheet	16	11	10
£38	7	2		£37	11	10

R.38

26 (Award)	5	0	To Income for year carried to Balance Sheet	58	19	2
33 (Surplus of Income)	15	5				
£60	0	5		£58	19	2

Edward Busk

21	0	0	To 1949 Award	21	0	0
4 (Surplus of Income)	6	1				
£25	6	1		£21	0	0

Wilbur Wright

75	0	0	To 1949 Award	75	0	0
13	3	10	„ Surplus of Income over Expenditure for year carried to Balance Sheet	5	18	4
£88	3	10		£80	18	4

Simms Gold

6 (Award)	17	6	To Income for year carried to Balance Sheet	16	7	4
10 (Surplus of Income)	8	2				
£17	5	8		£16	7	4

Alston

—	—	—	To 1949 Award	5	0	0
12 (Income)	6	4	„ Surplus of Income over Expenditure for year carried to Balance Sheet	3	18	2
£12	6	4		£8	18	2

Geoffrey de Havilland

66	14	6	To Income for year carried to Balance Sheet	66	14	6
£66	14	6		£66	14	6

TRUSTS LIMITED

for the Year ended 31st December 1949

Endowment Fund

1948 Figures					
£	s.	d.		£	s. d.
3379	18	6	By Interest on Investments (Gross)	3379	18 6
276	9	7	„ Interest on Investments (*less* Tax)	316	8 8
839	10	0	(Income Tax Refund)		
£4495	18	1		£3696	7 2

Memorial Fund

5	7	4	By Interest on Investments (Gross)	5	7 4
£5	7	4		£5	7 4

Memorial Fund

5	19	4	By Interest on Investments (Gross)	5	19 4
5	19	4		£5	19 4

Stuart Fund

38	7	2	By Interest on Investments (Gross)	37	11 10
£38	7	2		£37	11 10

Memorial Fund

60	0	5	By Interest on Investments (Gross)	58	19 2
£60	0	5		£58	19 2

Memorial Fund

15	17	0	By Interest on Investments (Gross)	15	17 0
5	1	5	„ Interest on Investments (*less* Tax)	4	15 4
			„ Excess of Expenditure over Income for year carried to Balance Sheet		7 8
4	7	8	(Refund of Income Tax)		
£25	6	1		£21	0 0

Memorial Fund

80	18	4	By Interest on Investments (Gross)	80	18 4
7	5	6	(Refund of Income Tax)		
£88	3	10		£80	18 4

Medal Fund

17	5	8	By Interest on Investments (Gross)	16	7 4
£17	5	8		£16	7 4

Memorial Fund

8	18	2	By Interest on Investments (Gross)	8	18 2
3	8	2	(Refund of Income Tax)		
£12	6	4		£8	18 2

Memorial Fund

66	14	6	By Interest on Investments (*less* Tax)	66	14 6
£66	14	6		£66	14 6

Income and Expenditure Accounts
Royal Aeronautical Society

1948 Figures				1949 Figures		
£	s.	d.		£	s.	d.
485	0	0	To Amortisation of Leasehold Property	485	0	0
213	15	0	„ Depreciation of Furniture	228	11	9
3797	3	1	„ Surplus of Income over Expenditure for year transferred to Royal Aeronautical Society	2982	15	5
£4495	18	1		£3696	7	2

Pilcher

5	7	4	To Income for year carried to Balance Sheet	5	7	4
£5	7	4		£5	7	4

Usborne

—	—	—	To 1949 Award	5	0	0
5	19	4 (Income)	„ Surplus of Income over Expenditure for year carried to Balance Sheet	19	4	
£5	19	4		£5	19	4

Herbert Akroyd

—	—	—	To 1949 Award	21	0	0
38	7	2 (Income)	„ Surplus of Income over Expenditure for year carried to Balance Sheet	16	11	10
£38	7	2		£37	11	10

R.38

26	5	0 (Award)	To Income for year carried to Balance Sheet	58	19	2
33	15	5 (Surplus of Income)				
£60	0	5		£58	19	2

Edward Busk

21	0	0	To 1949 Award	21	0	0
4	6	1 (Surplus of Income)				
£25	6	1		£21	0	0

Wilbur Wright

75	0	0	To 1949 Award	75	0	0
13	3	10	„ Surplus of Income over Expenditure for year carried to Balance Sheet	5	18	4
£88	3	10		£80	18	4

Simms Gold

6	17	6 (Award)	To Income for year carried to Balance Sheet	16	7	4
10	8	2 (Surplus of Income)				
£17	5	8		£16	7	4

Alston

—	—	—	To 1949 Award	5	0	0
12	6	4 (Income)	„ Surplus of Income over Expenditure for year carried to Balance Sheet	3	18	2
£12	6	4		£8	18	2

Geoffrey de Havilland

66	14	6	To Income for year carried to Balance Sheet	66	14	6
£66	14	6		£66	14	6

TRUSTS LIMITED

for the Year ended 31st December 1949

Endowment Fund

1948 Figures					
£	s.	d.		£	s. d.
3379	18	6	By Interest on Investments (Gross)	3379	18 6
276	9	7	„ Interest on Investments (*less* Tax)	316	8 8
839	10	0	(Income Tax Refund)		
£4495	18	1		£3696	7 2

Memorial Fund

5	7	4	By Interest on Investments (Gross)	5	7 4
£5	7	4		£5	7 4

Memorial Fund

5	19	4	By Interest on Investments (Gross)	5	19 4
5	19	4		£5	19 4

Stuart Fund

38	7	2	By Interest on Investments (Gross)	37	11 10
£38	7	2		£37	11 10

Memorial Fund

60	0	5	By Interest on Investments (Gross)	58	19 2
£60	0	5		£58	19 2

Memorial Fund

15	17	0	By Interest on Investments (Gross)	15	17 0
5	1	5	„ Interest on Investments (*less* Tax)	4	15 4
			„ Excess of Expenditure over Income for year carried to Balance Sheet		7 8
4	7	8	(Refund of Income Tax)		
£25	6	1		£21	0 0

Memorial Fund

80	18	4	By Interest on Investments (Gross)	80	18 4
7	5	6	(Refund of Income Tax)		
£88	3	10		£80	18 4

Medal Fund

17	5	8	By Interest on Investments (Gross)	16	7 4
£17	5	8		£16	7 4

Memorial Fund

8	18	2	By Interest on Investments (Gross)	8	18 2
3	8	2	(Refund of Income Tax)		
£12	6	4		£8	18 2

Memorial Fund

66	14	6	By Interest on Investments (*less* Tax)	66	14 6
£66	14	6		£66	14 6

REVIEWS

THE PROPERTIES OF METALLIC MATERIALS AT LOW TEMPERATURES. P. Litherland Teed. Chapman and Hall Ltd., London. 1950. 21s. net. 222 pp. Illustrated. Index.

Many people have seen a bar of mild steel break when dropped on the ground on a frosty morning; to warm an impact test piece, by carrying it in the trouser pocket for an hour or two before testing, is a recognised part of test-house technique. Most engineers are well aware of the fall in the strengths of metals which are heated; but not all realise the change in strength or toughness produced by cooling the material to sub-normal temperatures. Yet various components of an aircraft may be exposed in service to temperatures that are quite low, and a failure resulting from the development of brittleness at low temperatures is just as serious as one produced by over-heating.

Clearly, those concerned with the proper use of metals in modern aircraft, and the choice of the most suitable one for any particular service, must take account of the low temperature properties of the materials used. On this subject a good deal of information is available, but there are large gaps in the existing knowledge. The time was ripe for an examination of the data, for a critical appreciation of the present state of knowledge, and for an orderly statement of the facts—arranged for easy reference by the users of materials in conditions of intense cold. Such users are found in other branches of engineering besides aeronautics.

No better authority than the Royal Aeronautical Society, to sponsor such a publication, could be imagined; and no more competent authority than Major P. L. Teed could have been chosen to write it. In this volume, which is the first in a series of monographs on metallic materials published under the authority of the Society, the existing data is reviewed exhaustively. Matter from Government and private sources is incorporated along with the relevant published data. As a consequence, a complete picture is painted of the behaviour—at low temperatures—of all kinds of aircraft metals and alloys; and this book enables anyone interested to acquire all the knowledge likely to be needed.

Major Teed has treated his subject metal by metal; plain-carbon and alloy steels, aluminium and its alloys, magnesium and the alloys arising from it, copper and copper alloys, along with nickel, zinc, tin and lead, all are examined in turn. Adequate theoretical statements are provided; but the reader is likely to be interested chiefly in the copious tables, provided in each chapter, that reveal the properties of a great variety of metals at different temperatures, sometimes approaching to the absolute zero. The indications and trends suggested by these values are summarised in each chapter, the broad picture without trimmings being presented in a masterly way. Furthermore the author provides an exact reference for his every statement, thus equipping the interested reader to pursue further any item that interests him specially.

The monograph is admirably done and is entirely objective. It provides the available knowledge and reveals the gaps still to be filled. Obviously it is an essential item in the library of everyone interested in aircraft materials and their proper employment. Actually, our reference shelf rather than the library is likely to be the home of this book, for it will be consulted constantly. Its handy form—which disguises the wealth of matter within—is to be commended.

THE CONQUEST OF SPACE. Paintings by Chesley Bonestell, Text by Willy Ley. Viking Press, New York. $3.95. 160 pp. 18 figures, 48 plates (16 in colour).

All who have flown know that flying has more than a mere utilitarian value; it is the key which unlocks the door to a magic world where the sun and the moon shine on fantastic mountain ranges of cloud or on vast expanses of glittering,

sparkling ocean, and in which the earth, with all its toil and turmoil, shrinks to the status of an insignificant relief map. Perhaps if someone, in the late nineteenth century, had been able to give his contemporaries a preview of this world, then the poets and artists would have been even more ardent than in fact they were, in their yearnings that man should one day learn the secret of flight.

These thoughts are prompted by the beautifully-produced book now under review, because it performs a comparable service for the infant science of astronautics which, slowly but surely, is evolving from aeronautics. Bonestell's illustrations, drawn with uncanny photographic realism and a great regard for technical accuracy, introduce us to a world of bizarre beauty far surpassing even that of the airman. They depict what, on the basis of the best modern astronomical knowledge, we believe our children will see from their rocket craft, as they speed far above this planet or visit other ones in the Solar System. Also appearing in the paintings are some of the rocket craft themselves, looking extremely plausible and logical developments of the winged V.2 project. (Remembering the twists and turns taken by technical progress, perhaps they appear too convincing, to our eyes.)

In view of the reputation of American colour-printing, it is of interest to record that the publishers, seeking to do full justice to Bonestell's originals, came to this country for the blocks for those plates reproduced on the four-colour process. Even the black-and-white plates have a striking beauty, although naturally one wishes more were in colour. Expense presumably precluded this; as it is, the book is a remarkable effort at its present price.

In his text, Willy Ley repeats the success of his own "Rockets and Space Travel," describing the technicalities of rocketry, and the theoretical basis of the claim that space-flight will one day be practicable, in an excellent piece of popular scientific writing He also reviews existing astronomical knowledge of the Solar System, so that altogether the text provides an excellent background to the illustrations.

The publishers' dust-jacket carries the sub-title: "A Preview of the Greatest Adventure Awaiting Mankind," and the comment from Dr. Richardson (of the Mount Wilson and Palomar Observatories): "I only wish that a book containing such illustrations could have fallen into my hands when I was a youngster." Although not in any sense a juvenile work, this book, one feels sure, will indeed exert a great influence on many young minds. It is understood that there is a good chance of its being published in Great Britain, and it is very much to be hoped that this will be done.—A.V.C.

PRIVATE FLYING. W. T. Piper and D. J. Duffin. Pitman, New York. 1949. $4.50. 295 pp. Illustrations. Index.

PRIVATE PILOT'S HANDBOOK. A. G. Norwood. Pitman, New York. 1949. $4.50. 300 pp. Figures. Appendix. Index.

LEARNING TO FLY. Bert. A. Shields. Pitman, New York. 1949. $4.00. 262 pp. Illustrations. Index.

The titles of these books evoked the hope that English editions would supply the need for up-to-date publications for the post-war private pilot, with special reference to the new technical examinations. Unfortunately, the hope must remain unfulfilled.

Mr. W. T. Piper's "Private Flying" is addressed to the general public. Most of the book is an attempt to convince the man on the ground that the very light aeroplane is the ideal form of transport for all journeys between 50 and 800 miles, and for longer journeys off the trunk routes. Even allowing for the greater volume and freedom of movement between the United States of America than between the un-united states of Europe, Mr. Piper and his collaborator overstate their case.

For example, they ignore the effect of the weather on reliability, and of unreliability on their economics. It is interesting to note that the authors give 14 per cent. as the rate for comprehensive insurance, and 100,000 as the number of registered personal aircraft.

Nevertheless, the chapter entitled "How Private Flying Grew" (p. 32) is of such absorbing interest that it justifies the whole book. First, this chapter contains detailed sales and production records of American ultra-light aircraft from 1929 to 1949, including the War years. Secondly, it shows that the American military mind is at least as hidebound as the British, and that the application of American efficiency to red tape makes it even more effective in Washington than in Whitehall. Thirdly, it tells the story of private manufacturers who made provision to satisfy a national need that authority was unable to foresee. This story closely resembles one explanation I was given, some years ago, of our ability to convert our fixed-pitch Spitfires to constant-speed propellers in the short interval between the Battle of France and the Battle of Britain. The moral of both stories seems to be that omnipotence is dangerous without omniscience.

Commander A. G. Norwood, U.S.N.R., in the Second (1949) Edition of his "Private Pilot's Handbook," attempts to provide a complete text book for candidates for the U.S.A. Private Pilot's Licence. Half the book describes procedures and practical examples of journeys in such detail that their necessarily American nature renders this part useless elsewhere. The other half of the book contains some first-rate material the validity of which is universal, but which pre-supposes a higher standard of education than the average amateur pilot possesses. It suggests that the author is more accustomed to Service pupils.

The revision of the first edition to 1949 standards has not wholly eradicated 1942 values, and there are some notable omissions in both the theoretical and practical sections of the book, which are insufficiently correlated. For example, icing is only dealt with meteorologically, although the inclusion of a carburettor heater in so many small American aeroplanes indicates that carburettor icing, even with small engines, is an every-day risk in the U.S.A. The author ignores propulsion and engine-handling altogether. His chapter on Radio covers Navigational Aids, but leaves Approach Aids unnoticed.

Lt. Commander Bert A. Shields, in "Learning to Fly," ignores theory altogether. He is obviously a gifted practical flying instructor, accustomed to inculcating sound practice in his pupils by force of personality rather than by intellectual conviction. His book is addressed to an imaginary *ab initio* pupil, in the first person, and consists of a series of arbitrary instructions on the use of the controls or the manœuvres he wishes performed. It is not clear whether the sequence of instruction is a personal one or the standard U.S.A. version, but the incomparable A.P. 1732a has left room for a pupil's book which "Learning to Fly" does not fill, for it fails to supply the why and wherefore.

Members of the C.F.S. will be glad to know that the fame of the Gosport system has crossed the Atlantic. It consists of a pair of special earphones, developed by a flight instructor in the R.A.F. during World War I.—G.P.

THEORY OF WING SECTIONS. Ira H. Abbott and Albert E. von Doenhoff. McGraw-Hill. 1949. £6 0s. 0d. 693 pp. Figures. Appendix. Index.

During recent years considerable progress has been made in the research and development of wing sections and their characteristics to meet the demands for lower drags and higher speeds. The work in the U.S.A. and Great Britain has followed independent and characteristic lines; in the U.S.A. the emphasis has been on the development and systemmatic testing of a large number of families of aerofoils, while in Great Britain there has been a greater emphasis on exploiting and extending aerofoil theory and less on systematic experimental work.

Messrs. Abbott and Doenhoff have now collected the bulk of the American work and presented it in this book in a form which will be invaluable to the aeronautical engineer. Not only are the main experimental data exhaustively tabulated and presented in graphs, but the essentials of the theory are simply and clearly outlined, and a comprehensive list of references is provided for further detailed reading.

A summary of the subject matter is as follows. The application of section data to the estimation of the characteristics of wings of finite span is first discussed, and a number of spanwise lift distribution tables are given. Then the basic aspects of two-dimensional flow are dealt with briefly as a preliminary to a discussion of wing section theory, as developed by Theordorsen, Naiman and others, and the theory of thin wings. This is followed by a simple but effective discussion of boundary layer theory and the influence of boundary layers on aerofoil characteristics. The next chapter, describing the geometry of the various NACA families of aerofoils and explaining the bewildering varieties of notation that have been adopted, will be most welcome. This is followed by a discussion of the more important section characteristics and a detailed discussion of high lift devices. Finally, there is a chapter on compressibility effects at subsonic speeds.

Not only is the text most lavishly illustrated with diagrams and tables, but over half of the book is occupied with comprehensive appendices giving full details of the measured characteristics and ordinates of all important NACA sections, conventional or otherwise, and of the basic thickness forms and mean camber lines.

It would be possible to voice a few minor criticisms but nothing of serious import. The printing and layout are well up to the excellent standard of previous McGraw-Hill publications. It is a pity that the price is such that the sales in Great Britain are unlikely to be large. We now await with interest the book that should be nearing completion, detailing the parallel developments of aerofoil theory and practice in Great Britain.—A.D.Y.

CORRESPONDENCE

THE SERVICING OF AIRCRAFT

We have read with interest Mr. Crawley's paper (The Servicing of Aircraft: Choice of Principle and Procedure, December 1949 JOURNAL). In the light of our operating experience (250,000 flying hours a year) we should like to comment on some of the assumptions made. In particular, we refer to Fig. 2 of the paper.

Our experience is that with present servicing methods the ratio of unpreventable to preventable defects shown at Fig. 2*a* is much smaller than occurs in practice. It may be interesting to note that when we reduced the number of inspection items, so giving a 50 per cent. reduction in inspectional man-hours, there was no increase in the number of ensuing defects. Concerning Fig. 2*b*, although we do not know the relation between the *ad hoc* cost and the number of defects which still occur, we think that linearity is most unlikely. A similar comment applies to Fig. 2*c*, *i.e.* the ensuing cost against the number of defects which still occur.

We do not necessarily disagree with the general shape of Fig. 2*d*, but since *a*, *b* and *c* are inter-connected, we do not believe this figure can be obtained by a straightforward summation of the others. Neither do we expect the minimum to be critical.

In view of these comments, it may be of interest that during the past two years we have been observing the result of reducing the scope of the aircraft inspections and extending the period of time (flying hours) between them. Over this period we have been increasing the size of our flying effort, and as can be seen (in Fig. 1) the number of man-hours spent on servicing (inspecting and repairing) has consistently decreased.

We believe this reduction in man-hours has been effected by the following four factors—

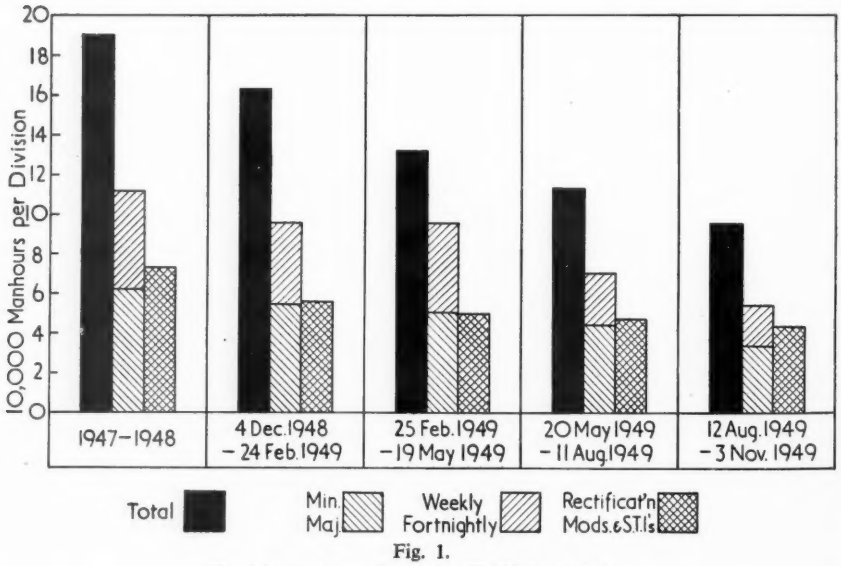


Fig. 1.
Servicing cost man hours for 50,000 hours flying.

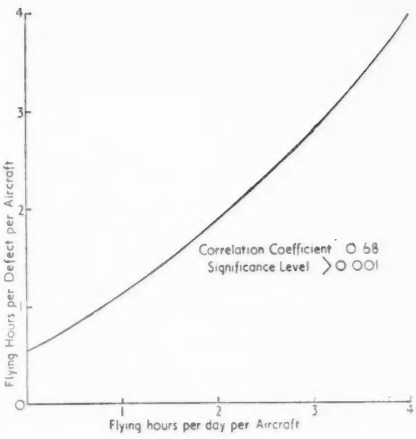


Fig. 2.

Lessening of flying hours for defects on flying hours a day.

(*a*) The lowering of the number of man-hours spent on pure inspection.

(*b*) The reduction in inspection work which has meant less disturbance to the aircraft with a corresponding reduction in the defects sometimes caused by such disturbances; *e.g.* on the Wellington aircraft, the defect rate in the first ten flying hours after the normal periodic inspection (minor servicing) dropped by 20 per cent. after the reduction in inspection work.

(*c*) An increase in the intensity of usage of each aircraft, which has led to a lower defect rate per flying hour. This is illustrated by Fig. 2. An alternative explanation that when the defect rate was low, more time was left in which to fly the aircraft (*i.e.* higher intensity) was discarded, since this would mean that for an increase of intensity the time the aircraft spent unserviceable must decrease, and this did not occur. The correlation coefficient for the same sample as was used for Fig. 2 was +0.1, and for acceptance of the alternative explanation it would have to be negative and of the order of 0.2.

(*d*) Increased efficiency in servicing methods and organisation, in particular more economic employment of the available skilled tradesmen, has undoubtedly contributed to the reduction.

All the results of our analyses are at the moment empiric, but we have collected many, as yet undigested, thoughts on the theoretical aspect of the problems, which we hope to present at some future date.

J. W. BAYLEY, Wing Commander, Tech. Plans.

R. H. COLLCUTT, B.Sc.(Eng.), Research 2.
R.A.F. Flying Training Command.

MR CRAWLEY'S REPLY

I am sorry that the sketch diagrams in my paper (December 1949 JOURNAL, pages 1,100-4) have been misunderstood. Perhaps I over-condensed their explanatory titles.

The sketches are not a substitute for the text of the paper. Nor are they "assumptions." They are no more than rough illustrations of certain matters referred to incidentally in the text: they show only general graphical forms and trends, and the text can be read equally well without them. Needless to say, the extreme ends of the curves would never be reached in reasonable practice.

Messrs. Bayley and Collcutt evidently suppose the abscissae in my sketches to represent mere numbers of defects. They seem to consider a measure of this sort valid and meaningful. But I intended and wrote no such thing. It is absurd to add up indiscriminately a number of individual defects of all kinds, without any classification, and expect to draw therefrom any basic conclusion whatever. It is as if a bank tried to measure its cash balance by counting each separate coin in its coffers as one unit. The position is indeed worse than this, because the very

existence of a "defect" depends upon what rules and habits happen to be in force at any given time and place, not to mention such factors as the psychological effect of operating intensity upon defect recording.

Each individual defect must be suitably weighted before it can rationally be "added" to another defect of a different kind. For some purposes a good rough-and-ready way of weighting a defect of any particular class is to multiply it by the average man-hours needed to rectify it: for other purposes it is better to use as a multiplying factor the average hours needed for the rectification. Because the ordinates of my sketches (*a*) and (*b*) are concerned with cost of servicing, they are based upon an elaboration of the former method of weighting defects. Because the abscissae are concerned with achievable machine utilisation, they are based upon the latter method. Accordingly, instead of writing against the horizontal axis "Defects that still occur," I might have written more explicitly: "Number of hours of operation lost out of a typical fixed period of possible operation, through defects that still occur and have to be rectified *ad hoc*." Had I done so, perhaps Messrs. Bayley and Collcutt would not have gone so badly astray in their second paragraph.

Thus, roughly speaking, the abscissae of my Fig. 2 are a measure of flying time lost through *ad hoc* defects arising in the "in-use" aircraft—by which I mean those aircraft which are not in process of undergoing any prearranged inspection or other prearranged special work. But, even with a reasonable interpretation of this kind, I do not claim that my sketches would be found accurate and invariable in practice, any more than the writers would claim that the fitted smooth curve they have drawn in their Fig. 2 was exactly fulfilled in all practical circumstances. For example, the relative position of the vertical broken line or limit in my sketch 2(*a*) is undoubtedly different for the R.A.F. from what it is for the U.S.A.F., and so are the relative slopes and shapes of the various functional lines. There are even differences for separate Commands, and for other varying circumstances, depending upon the organisation and the type of aircraft and flying work. Commercial flying concerns can show differences again. My sketches are general in form, but their details depend upon the particular conditions.

A matter of real import was my failure to mention that the "Preventive cost" ordinate for aircraft, in my sketch 2(*a*), must itself generally include an allowance for the value of the aircraft-hours, and so on, lost *during the inspections*—and during any other prearranged special work such as design modifications. (For other kinds of machinery this allowance is rarely necessary, as inspections can generally be planned to take place at times which are not "periods of possible operation," *i.e.* when there would anyway be no productive output from the machine concerned.) On this information—which, because it was not self-evident, I now offer with an apology—I hope Messrs. Bayley and Collcutt can agree with me that a total cost shown in my sketch 2(*d*), in specified conditions, is equal to the sum of its parts (*a*), (*b*) and (*c*) in the same conditions. Naturally the parts are "inter-connected": so are the courses of a dinner, but the waiter has no difficulty in adding up the bill. I hope further that the writers will apply the same simple rule of arithmetic when they come to re-draw their own Fig. 1.

The condition for minimum total cost in the case of aircraft may or may not be critical, *i.e.* located at a fairly sharp bend in my curve 2(*d*): I do not claim that it is always so, and in any event the sharpness of a bend is a relative and subjective idea. What is clear from common sense, and is also supported by the writers' own observations, is that the left arm of the total cost curve will rise steeply from the minimum and is therefore to be avoided in practice by all means. An opinion regarding the steepness of the right arm of this curve needs to be backed by some idea of what is meant by "ensuing cost" and of how to estimate its magnitude.

As my sketches attempt to convey many ideas in a small space, they are correspondingly easy to criticise. For example, the writers' finding (*b*) in their

penultimate paragraph implies that, for their early conditions, the top left part of my curve 2(*a*)—and therefore also of 2(*d*)—would have shown the beginning of a curl towards the right again: this may well be so, and it neatly illustrates the extravagance of over-inspection. No practical man would be puzzled by this, nor regard it as an inexplicable ambiguity. And so on. Much depends upon one's viewpoint. The viewpoint taken in my paper is practical and economic: the work of Messrs. Bayley and Collcutt has been, as they say, empiric. They have been further handicapped by dealing only with the limited and expensive field of low average flying intensities; and naturally, if the figure of "possible operation" is arbitrarily limited, the "ensuing cost" ordinates must be inflated throughout my sketch 2(*c*), in order to cover the operation which is deliberately lost as well as that which is lost by *ad hoc* servicing. A figure expressing some part of the so-called cost of a flying hour is of little value when nothing is stated regarding the cost of a non-flying hour.

I do complain, however, that from the economic viewpoint the construction of the writers' Fig. 1 is almost worthless, nor that the co-ordinates chosen for their Fig. 2 seem to conceal rather than reveal what practical information it contains. I recognise that their viewpoint is different.

I turn now to the statistical observations on which the writers have been employed, some results of which they outline in the last three paragraphs of their letter. Most of these results are of immediate importance to R.A.F. Flying Training Command and deserve credit accordingly. Some of the implications are also worth noting.

The writers tacitly admit that the old servicing schedules as applied in 1947-8 were needlessly complicated, particularly with regard to inspections (*i.e.* servicing work intended to be preventive). See the findings (*a*), (*b*) and (*d*) in their penultimate paragraph, and their Fig. 1, and also the reference in their second paragraph to a 50 per cent. reduction in inspectional man-hours. These serve aptly to illustrate Sections 4 and 5 of my paper, where the extravagance of ossified servicing schedules is repeatedly stressed and particularly their tendency to lead to "'preventive' work that in fact prevents nothing" (*loc. cit.*, page 1,103, bottom of column 1). It is, as a matter of fact, understandable and excusable that such conditions should have taken hold in 1947, after a difficult period of imperfect organisational adjustment due to unbalanced post-war contraction of the R.A.F.

But, unless proper precautions are taken, servicing schedules are liable to become ossified in any flying organisation—particularly a military one—at any time. New aircraft and fresh operating policies keep coming into use, and with them new conditions. How is one to prevent similar troubles from recurring spontaneously? Any particular servicing schedule that Messrs. Bayley and Collcutt may recommend from their present findings will be as obsolete in three years' time as the 1947 schedule is today. And in general, any new servicing schedule set up without proper defect statistics begins to be obsolete the day it is born. Nor can one trust blindly, for the future, to some such pious maxim as: "Keep on inspecting your aircraft less and flying them more."

As my paper indicates, what is needed is a rational servicing *principle*, sufficiently simplified for practical men to adapt it fairly easily to any given aircraft in any given circumstances, and controlled by proper defect statistics (*loc. cit.*, lower part of page 1,102). I emphasise that the principle must be simple: it is no good expecting practical men to have time in their daily work for distinguishing between, and applying separately, some ten or twenty different statistical life functions. The paper reduces the essential types to two extremely simple ones, for either of which the measurement of the life of an aircraft part is to be based upon flying hours, sorties or calendar period according as experience and technical "know-how" shows to be appropriate. (In order to eliminate a possible misunderstanding at this point, I want to stress that neither my paper nor the present notes have any bearing upon "machine design for reliability." That is an entirely separate,

important and large subject, which may require its own especially detailed life records, even to the extent of treating "defects" and "failures" separately: Mr. J. D. North and others have given me much information upon it. Here I am considering throughout only the question of how servicing policy should deal in practice with the upkeep of *given* machines.) I assume only a broad and simple classification of parts: for this purpose it is sufficient to divide any given aircraft into not more than fifty parts or components, and not all of these will need to be "lifed" statistically.

Naturally there is the alternative course—somewhat bleak and slippery—of continuing for ever, as a permanent feature of servicing policy, the sort of work the writers have been doing. This, however, is not the place to discuss such a course and its merits.

The writers' finding (*c*), with their Fig. 2, confirms an already widespread belief that some defects "pop up" at a roughly constant calendar rate, upon aircraft that are used appreciably but not much, like mushrooms in a cellar. Except at the lowest flying intensities, the rate of growth the writers illustrate is one defect per aircraft per day. This effect may be denied in some quarters—it is complex and arguable, because much depends upon what determines the existence of a "defect"—but it is interesting to find here some statistical support for it. If the effect be accepted as real, the economic remedy has always been self-evident: do more flying, or keep less aircraft. In a military organisation, operating policy must determine to what extent the remedy can be applied. (It is permissible to ignore the "empiric" remedy indicated by the extreme left of the writers' Fig. 2, which would consist in never flying aircraft at all and never inspecting them at all.)

It is not surprising that the writers' "many thoughts on the theoretical aspect of the problems" remain "as yet undigested," because the problems on which they have been employed—see their fourth paragraph—have no theoretical aspect. A little mental flatulence is to be expected in consequence. The work outlined in their communication has in fact determined, by hit-or-miss methods, the most appropriate servicing and operating schedules for their particular Command to use during the particular year 1950. The methods used are ill adapted to furnish basic information of long-term practical value, but this may have been unavoidable. As a record of the Command's progress since 1947 the work commands respect, and those who have been employed in it are to be congratulated upon its successful outcome.

B. CRAWLEY.

AIRCRAFT WEIGHT

Mr. Rosenthal's paper on "The Weight Aspect in Aircraft Design" (JOURNAL, March 1950) shows an encouraging trend towards an examination of all sources of aircraft weight. With regard to structural weight Mr. Rosenthal (p. 191) emphasises the importance of distinguishing between "design efficiency" and "structural efficiency," stating that "the first is a matter for the project office and the second a matter for the stress office." In my opinion we should try to avoid distinctions of this sort; the ideal situation would be to have every designer well trained in design, stress, weight, and production. Then it would be possible to design every part so as to achieve the proper balance between function, strength, weight, and cost. Since it is apparently impossible to acquire such a design staff, we must resort to specialisation. A high degree of specialisation, however, tends to hinder the compromising process by creating different points of view, which in turn result in almost endless arguments. Perhaps the most important objective in engineering organisation and management is to secure the benefits of specialisation without its disadvantages.

One technical point should be noted. On page 192 it is stated that the fuselage weight "is shown to vary with the square root of the fuselage gross surface area."

Without benefit of Fig. 3 on the following page this statement would be quite misleading, since the curves plotted against the square root of area are not linear. If the curves are replotted against area they become almost linear, except for an intercept on the area axis. A typical equation which approximately represents Mr. Rosenthal's curves is:—

$$\text{Fuselage weight (lb.)} = 3.15\ (S - 500)$$

where S is surface area in square feet.

The value of 3.15 lb./sq. ft. corresponds roughly to an aluminium sheet 0.22 in. thick, which appears reasonable, since the fuselage structural weight includes stringers and frames. It is more difficult to see why the straight line does not go through the origin: apparently the first 500 square feet, on a large fuselage, are "free"!

Mr. Brown's paper on "The Reduction in Weight of Structurally Important Aircraft Components by Controlled Cold-Working During Manufacture" (JOURNAL, March 1950) reminds me of some tests made at Consolidated-Vultee Aircraft Corporation (San Diego) over ten years ago. It was found that pre-stretching, although helpful, was much less effective than pre-compression in raising the compressive yield stress. Since much of the wing structure is critical in compression, the compressive yield stress establishes a rough upper limit for the allowable stress. Much work has been done in the United States on the effects of pre-tension and pre-compression. In fact, the stretching of sheet to a minimum prescribed value is an integral part of the treatment of 24ST aged sheet. (This practice has been largely replaced by the use of the 75ST alloy, which requires no pre-stretching.)

Perhaps I should have included "metallurgist" in the list of qualifications for the ideal designer. At any rate the metallurgist who makes recommendations on structural materials should be thoroughly acquainted with the conditions which may exist within the structure (*e.g.* combined stresses, stress concentration, repeated loading, temperature effects, cold working, and so on). If the gap which exists between the stressman and the metallurgist could be bridged I believe many of the long-standing arguments about ductility, yield stress, notch-sensitivity and fatigue would disappear.

F. R. SHANLEY,
Professor of Engineering, University of California.

MR. ROSENTHAL'S REPLY

My main reason for distinguishing between "Design Efficiency" and "Structural Efficiency" was to draw attention to the fact that the two things had, in my opinion, been very much confused and that the stressmen had been blamed for inefficient structural design, which, in fact, was due to lack of design efficiency.

As a weight engineer, I am well aware that the designer trained in design, stressing, weights, production, and so on, is the ideal, but since we must resort to specialisation the relative functions of the project engineer and the structure engineer need sharply defining, in order that one does not get blamed for the sins of the other.

The curve plotting fuselage weight against the square root of the surface area was produced on what appeared then, to be the simplest possible bases and I welcome the suggestion that similar accuracies could have been obtained by plotting fuselage weight directly against surface area, although I cannot agree that the curve is linear except at the lower end. I find that the very large fuselages also become relatively heavier.

The point about the "free" 500 sq. ft. is intriguing and appears to be connected with the limitations of attempting to determine the weights of small fuselages from

data applying to aircraft of much larger dimensions. In this connection, it is interesting to note that the curves of window weight, door weight and flooring weight, plotted against fuselage surface area, tend to intercept the area axis at approximately 500 sq. ft. This becomes particularly obvious if the data used are limited to that for aircraft having 30,000 lb. gross weight and over.

Perhaps further investigations along these lines might shed some light on the point.

L. W. ROSENTHAL, *Associate Fellow.*

REDUCTION IN WEIGHT BY COLD-WORKING

It is almost impossible to present a very complicated subject in a short readable paper, such as that by Mr. Brown ("The Reduction in Weight of Structurally Important Aircraft Components by Controlled Cold-Working During Manufacture," JOURNAL, March 1950), and at the same time make it a completely comprehensive account. This letter is an attempt to clear some ambiguities which have crept into this paper and also to provide some additional information which may prove useful.

The aluminium producers have examined the problem of improving properties by judicial cold working, at different stages of production, with varying degrees of success for some years. In America, cold-working material in the intermediate solution treated state is practised on a commercial scale, as for example Alcoa 24ST86 sheet.

There are two ways in which the strength properties can be improved, the first is by raising the properties directly by cold work, and the second is by using the cold work to change the characteristics of subsequent heat treatment processes. Considering the latter aspect first, different alloys respond to this treatment in different ways. Fig. 1 shows the effect of cold rolling several sheet materials, and it can be seen that the high strength alloys of D.T.D.546 and D.T.D.363 compositions do not show large increases in tensile strength. The points for this graph were chosen from extensive artificial ageing tests at various times and temperatures, and represent the properties which were associated with the maximum proof stresses, corresponding to the stated degrees of cold work, which could be obtained.

Extruded materials behave in a similar manner to sheet (Fig. 2) although the cold work was provided by stretching in these cases. It should be pointed out that the fall in properties with large degrees of deformation is not necessarily significant. These results were obtained from relatively few tests and, since cold work increases the rate of ageing, the lower values were probably due to over-ageing.

These two figures show that although it is possible to increase the tensile strength by cold work after solution heat treatment, but before artificial ageing, the final properties of the alloys D.T.D.363 and D.T.D.364, are not improved sufficiently to warrant this extra treatment. The improvements in the earlier alloys are not great enough to enable them to replace these more modern ones.

To improve the strength properties it is necessary, therefore, to stretch these alloys in the fully heat treated state. Unfortunately, as shown in Fig. 3, the tensile strength is improved at the expense of the elongation which becomes very low for the alloy considered, namely D.T.D.364. Also, aluminium alloys are subject to the Bauschinger effect which provides a further disadvantage of stretching, for while the tensile proof stresses are raised, the compressive proof stresses generally become lower. Artificial ageing, while reducing this effect, does not entirely eliminate it. A summary of some of the published information is given in Reference 2. Other work on a D.T.D.363 alloy has shown that the compressive properties are reduced to a greater extent than in the Al-Cu-Mg alloys.

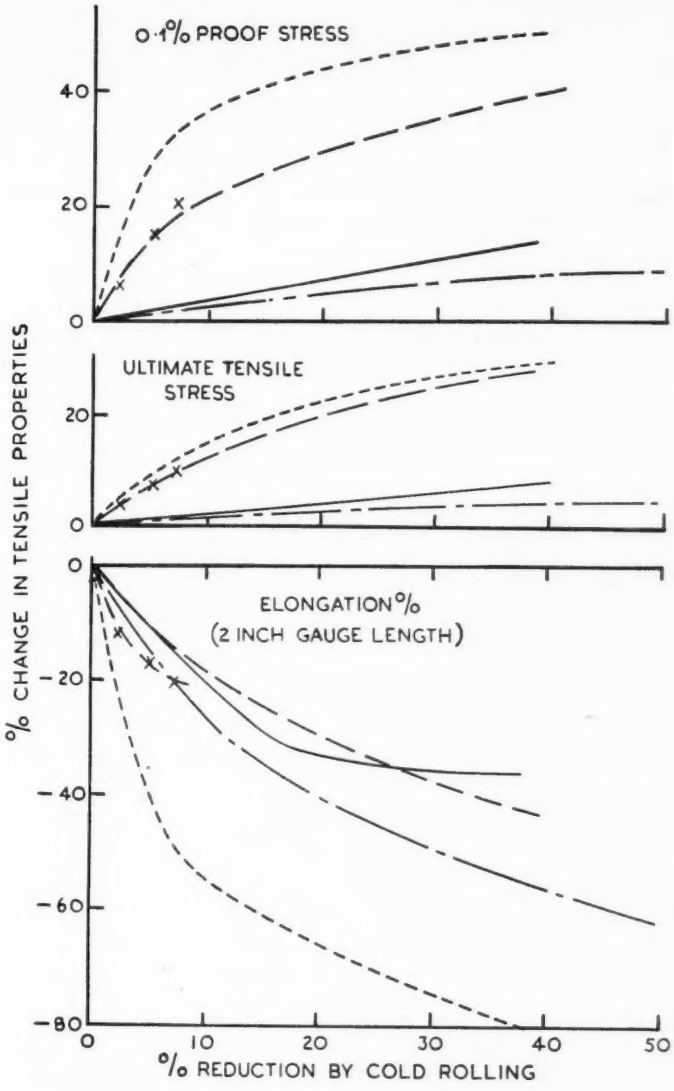


Fig. 1.

Effect of cold work between solution heat treatment and artificial ageing on the tensile properties after full heat treatment of several sheet materials.

Ordinates: Per cent. change in tensile properties. Abscissæ: Per cent. reduction by cold rolling.

Legend:
- - - - - - - Uncoated 24S type.
— — — — D.T.D.390 composition.
× — — — D.T.D. 390 composition cold worked by stretching.
———— D.T.D.546 composition.
—— - —— D.T.D. 363 composition.

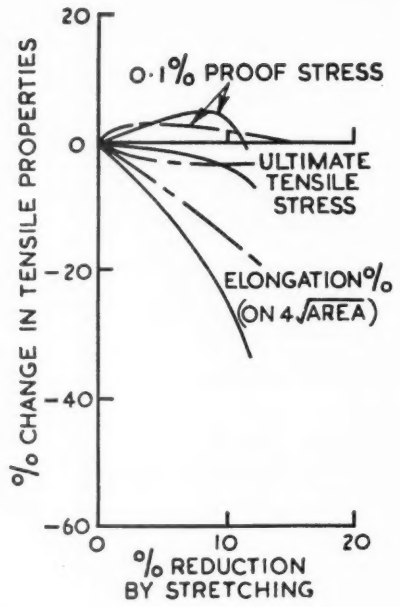


Fig. 2.

Effect of cold work between solution heat treatment and artificial ageing on the tensile properties after full heat treatment of two extruded materials.

Ordinates: Per cent change in tensile properties.

Abscissæ: Per cent. reduction by stretching.

Legend: ——— D.T.D.364 composition.
— - — D.T.D. 363 composition.

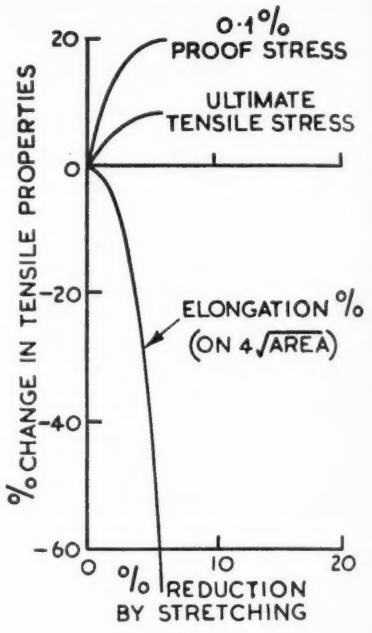


Fig. 3.

Effect of cold work after full heat treatment on the tensile properties after full heat treatment of D.T.D.364 extruded material.

Ordinates: Per cent change in tensile properties.

Abscissæ: Per cent. reduction by stretching.

Each curve:
D.T.D.364 composition.

With regard to residual stresses, stretching, *i.e.* uniform tensile strain, will not produce any residual stresses, but on the contrary tends to reduce those which are already present. It is plastic flow which is not uniform across the section which produces residual stresses, and these are high only when elastic strain is also present in some part of the cross-section. On a minor point of correction, residual stresses which are present at the solution heat treated stage, are not entirely relieved by artificial ageing, the maximum reduction in stress which can be expected is 30 per cent., a figure which will vary with the alloy[1].

The fatigue properties of D.T.D363 and D.T.D.364[3] alloys have been found to be decreased slightly by cold work. However, non-uniform plastic deformation applied during forming, with its consequent residual stress system, may seriously impair the fatigue properties.

REFERENCES

1. BENSON, L. E. Control of Internal Stresses in Heat Treated Aluminium Alloy Parts. *Journal of the Institute of Metals*, vol. LXXII, 1946, p. 501, and Discussion p. 669.
2. FORREST, G. and SMITH, F. R. C. Aluminium Alloys. Their properties and some of their applications to structures. *The Structural Engineer*. December 1948.
3. MINISTRY OF AIRCRAFT PRODUCTION. Scientific and Technical Memorandum No. 2/42.

K. GUNN,
(Aluminium Laboratories Ltd.).

MR. BROWN'S REPLY

I am indebted to Mr. Gunn for his very interesting contribution and clarification of some of the points raised by the subject of cold-working of high strength aluminium alloys, and for the useful additional information which he and Professor Shanley give.

From the point of view of the aircraft constructor, it is considered that the improvement obtainable by cold-working sheet materials would warrant the extra treatment involved, particularly as it is seen from the curves given that the 0.1 per cent. Proof Stress shows a greater increase than the Ultimate Tensile Stress, and it is the former property which is usually of more interest in aircraft design. The difficulties in the way of consistent production of such higher strength alloys, in anything other than perhaps sheet, would be very great indeed.

It is agreed that it is not so certain that the benefits conferred by cold-work will be as great when considered in its application to the extruded materials of D.T.D.364 and D.T.D.363 composition, since the slight improvement in 0.1 per cent. Proof Stress is outweighed by the disadvantage of a decreased ultimate tensile stress. This leads to a further point, which is that although the graphs for the sheet materials were constructed from points chosen from extensive artificial ageing tests, it is stated that the curves shown for extruded materials of D.T.D.364 and D.T.D.363 composition were constructed from relatively few tests, and it is suggested that the fall in properties might be due to over-ageing. Extensive tests involving varying the time/temperature of artificial ageing might result in a more optimistic view of the possibilities of improved properties.

Cold-working in the full heat-treated state was excluded in the paper; this was considered to rule out the possibility of serious trouble with the Bauschinger effect. The correction referring to residual stresses is accepted, and I would like to correct also the impression given in the paper that no investigations had been made into the fatigue and other characteristics of cold-worked heat-treatable alloys. Evidently a great deal of work has been done in this direction, and Professor Shanley's observations confirm this.

The comment Professor Shanley makes about pre-stretching and pre-compression is interesting, and makes one wish that it were possible to apply both treatments to one and the same piece of material!

However, in such components as are subjected to bending in service, it should be possible by collaboration between both stressman and metallurgist to decide whether it is in tension or compression that the higher properties are required, and then to give either pre-stretching or pre-compression to suit, varying the section shape to compensate for that part which possessed the lower properties. This could be done while still retaining the section uniform along its length during the early

stages of manufacture, which would be a pre-requisite of the cold-working, any taper, and such like, being machined afterwards. It is considered that this procedure would still result in a net saving in weight.

There is one further aspect which I feel should be made clear. It is not proposed that the property of Elongation per cent. be thrown overboard, and there is no question of it being considered desirable to relax this requirement with the other tensile properties standing as they are at present. Rather it is proposed to sacrifice some elongation per cent. *in exchange* for higher proof stress and ultimate tensile stress values.

J. G. H. BROWN, *Associate.*

an appreciation

THE COUNCIL OF THE ROYAL AERONAUTICAL SOCIETY WISH TO THANK THOSE COMPANIES WHO, BY THEIR GENEROUS CO-OPERATION, HAVE DONE SO MUCH TO HELP IN THE PRODUCTION OF THE JOURNAL

AEROPLANE & MOTOR ALUMINIUM CASTINGS LTD.

ALUMINIUM GRAVITY DIE CAST CYLINDER HEAD

SIR W. G. ARMSTRONG WHITWORTH AIRCRAFT LTD.

SIR W. G.
ARMSTRONG WHITWORTH
AIRCRAFT LIMITED

AIRCRAFT MATERIALS LTD.

AML

STRUCTURAL MATERIALS
and COMPONENTS

AUTOMOTIVE PRODUCTS CO. LTD.

ALL-BRITISH
Lockheed
hydraulics

AIRWORK LTD.

AIRWORK
LIMITED

AVIATION DEVELOPMENTS LTD.

AVIATION DEVELOPMENTS LTD
KINGSBOURNE HOUSE
HIGH HOLBORN, LONDON WC1
Specialists in Blind Riveting and Fastening Devices

ARMSTRONG SIDDELEY MOTORS LTD

ARMSTRONG
SIDDELEY

BLACKBURN & GENERAL AIRCRAFT LTD

BLACKBURN & GENERAL

BOULTON PAUL AIRCRAFT LTD.

BPA

DUNFORD & ELLIOTT (SHEFFIELD) LTD.

Dunelt
Special steels
FOR AIRCRAFT

THE BRISTOL AEROPLANE CO., LTD.

"Bristol"

DUNLOP RUBBER CO., LTD.

DUNLOP

BROOM & WADE LTD.

"BROOMWADE"
AIR COMPRESSORS
AND PNEUMATIC TOOLS

ELECTRO-HYDRAULICS LTD.

EH
LIMITED

DAVID BROWN & SONS (Huddersfield) LTD.

DAVID BROWN
& SONS (HUDDERSFIELD) LIMITED

Proprietors of
THE DAVID BROWN FOUNDRIES COMPANY
THE DAVID BROWN TOOL COMPANY
THE KEIGHLEY GEAR COMPANY
THE COVENTRY GEAR COMPANY

Subsidiaries
DAVID BROWN—JACKSON LTD.
DAVID BROWN MACHINE TOOLS LTD.
DAVID BROWN GEARS (LONDON) LTD.
PRECISION EQUIPMENT (PTY) LTD.
DAVID BROWN & SONS S.A. (PTY) LTD.

THE ENGLISH ELECTRIC CO. LTD. LONDON

'ENGLISH ELECTRIC'

MANUFACTURERS OF AIRCRAFT, AIRCRAFT ELECTRICAL EQUIPMENT, WIND TUNNEL DRIVES, TEST PLANTS FOR RECIPROCATING AND TURBINE-TYPE ENGINES, SUPERCHARGERS, COMPRESSORS, ETC.

DOWTY EQUIPMENT LTD.

DOWTY

UNDERCARRIAGE AND
HYDRAULIC EQUIPMENT

THE FAIREY AVIATION CO. LTD.

FAIREY

HIGH-PERFORMANCE SERVICE AIRCRAFT

Telephone No: SHEFFIELD 42051

THE HESTON AIRCRAFT CO., LTD.

FOLLAND AIRCRAFT LTD.

HAMBLE, SOUTHAMPTON

H. M. HOBSON LTD.

Hobson

GLOSTER AIRCRAFT CO., LTD.

F. A. HUGHES & CO. LTD.

Distributors of

ELEKTRON

REGISTERED TRADE MARK

MAGNESIUM ALLOYS

HANDLEY PAGE LIMITED

THE HUGHES-JOHNSON STAMPINGS LTD.

HAWKER AIRCRAFT LTD.

HAWKER

HYMATIC ENGINEERING CO. LTD.

Hymatic

COMPRESSED AIR EQUIPMENT

IMPERIAL CHEMICAL INDUSTRIES LTD.
(METALS DIVISION)

ICI

KELVIN & HUGHES (AVIATION) LTD.

K·B·B

(KELVIN BOTTOMLEY & BAIRD LTD.)

INTEGRAL LTD.

INTEGRAL
HYDRAULIC PUMPS
AND EQUIPMENT

LIGHT-METAL FORGINGS LTD.

LM
F

IRVING AIR CHUTE OF GREAT BRITAIN LTD.

AIR CHUTES
IRVIN

LODGE PLUGS LIMITED

LODGE
AVIATION
SPARKING PLUGS

K.L.G. SPARKING PLUGS LTD.

K·L·G
SPARKING PLUGS AND
IGNITION EQUIPMENT

MARTIN-BAKER AIRCRAFT CO. LTD.

MB
AV

KELVIN & HUGHES (AVIATION) LTD.

REGISTERED TRADE MARK
HUSUN
HENRY HUGHES & SON LTD LONDON

(HENRY HUGHES & SON LTD.)

D. NAPIER & SON LTD.

N

THE PALMER TYRE LTD.

'First in the Air'

Palmer

Penfold Street, Edgware Road, London, N.W.8

ROLLS-ROYCE LTD.

ROLLS-ROYCE

AERO-ENGINES

PERCIVAL AIRCRAFT LTD.

ROTAX LTD.

ROTAX

AIRCRAFT ELECTRICAL ENGINEERS

PETO & RADFORD

DAGENITE

AIRCRAFT BATTERIES

SAUNDERS-ROE LTD.

SAUNDERS-ROE LTD

OSBORNE, EAST COWES, ISLE OF WIGHT

Telephone: Cowes 445

THE PULSOMETER ENGINEERING CO. LTD.

SERCK RADIATORS LTD.

SERCK

A. V. ROE & CO. LTD.

SHORT BROTHERS & HARLAND LTD.

Shorts

Established 1908

THE FIRST MANUFACTURERS OF AIRCRAFT IN THE WORLD

SKYHI LTD.

SKYHI

VOKES LTD.

AMBER CROSS
TRADE MARK
Symbol of complete protection by Vokes Filters

SMITHS AIRCRAFT INSTRUMENTS LTD.

SMITHS

WESTLAND AIRCRAFT LTD.

WESTLAND AIRCRAFT LIMITED
Yeovil, Somerset

THE SPERRY GYROSCOPE CO. LTD.

SPERRY

A. C. WICKMAN LTD.

A.C. Wickman LIMITED
COVENTRY • ENGLAND •
SPECIALISTS IN MACHINE TOOLS & SMALL TOOLS FOR THE AIRCRAFT INDUSTRY

STERLING METALS LIMITED

STERMET
REGD TRADE MARK

YORKSHIRE ENGINEERING SUPPLIES LTD.

BRONZE FOUNDRIES

YESEATONIA

BEARINGS AND BUSHES

THE UNITED STEEL COMPANIES LIMITED

"FLYING FOX"
ELECTRIC STEELS

S. FOX & CO. LTD. SHEFFIELD

DIRECTORY OF ADVERTISERS

ACCLES & POLLOCK LTD.	Paddock Works, Oldbury, Birmingham	Broadwell 1500
AEROPLANE & MOTOR ALUMINIUM CASTINGS LTD.	Wood Lane, Erdington, Birmingham	Erdington 2207-9
AIRCRAFT MATERIALS LTD.	Midland Road, London, N.W.1	Euston 6151
AIRSPEED LTD.	The Airport, Portsmouth	Portsmouth 74631
AIRWORK LTD.	15 Chesterfield Street, London, W.1	Grosvenor 4841
ALBRIGHT & WILSON LTD.	49 Park Lane, London, W.1	Grosvenor 1311
ALVIS LTD.	Holyhead Road, Coventry	Coventry 5501
ARMSTRONG SIDDELEY MOTORS LTD.	Parkside, Coventry	Coventry 4061
ARMSTRONG WHITWORTH AIRCRAFT, SIR W. G., LTD.	Whitley, Coventry	Tollbar 2261 (15 lines)
AUTOMOTIVE PRODUCTS CO. LTD.	Tachbrook Road, Leamington Spa	Leamington Spa 1700
AVIATION DEVELOPMENTS LTD.	229 High Holborn, London, W.C.1	Chancery 8601
BIRMINGHAM ALUMINIUM CASTING (1903) CO. LTD.	Birmid Works, Smethwick, Birmingham, 40	Smethwick 1431
BLACKBURN AND GENERAL AIRCRAFT LTD.	Head Office: Brough, E. Yorks.	Brough 121
	Feltham Factory: Feltham, Middlesex	Feltham 3636
	London Office: 43 Berkeley Square, W.1	Grosvenor 5771-8
BOOTH, JAMES & CO. LTD.	Argyle Street Works, Nechells, Birmingham, 7	Birmingham E. 1221
BOULTON PAUL AIRCRAFT LTD.	Wolverhampton, Staffs.	Fordhouses 3191
BRISTOL AEROPLANE CO. LTD., THE	Filton House, Bristol	Bristol 48051
BRITISH BELTING AND ASBESTOS LTD.	Cleckheaton, Yorks.	Cleckheaton 800
BRITISH MESSIER LTD.	59 Southwark Street, London, S.E.1	Hop. 0192
BRITISH OVERSEAS AIRWAYS CORPORATION	Cheltenham Road East, Gloucester	Churchdown 3281
	Headquarters: Stratton House, Stratton Street, W.1	Mayfair 6611
	Traffic Enquiries: Airways Terminal, Buckingham Palace Road, S.W.1	Victoria 2323
BRITISH THOMSON-HOUSTON CO. LTD.	Lower Ford Street, Coventry	Coventry 4104
BROOM & WADE LTD.	High Wycombe, Bucks.	High Wycombe 1630
CHAPMAN & HALL LTD.	37 Essex Street, Strand, London, W.C.2	Central 2801
DAVID BROWN & SONS (HUDDERSFIELD) LTD.	Park Gear Works, Huddersfield	Huddersfield 3500
DAVID BROWN FOUNDRIES COMPANY	Penistone, near Sheffield	Penistone 135
DE HAVILLAND AIRCRAFT CO. LTD., THE	Hatfield Aerodrome, Herts.	Hatfield 2345
DOWTY EQUIPMENT LTD.	Cheltenham, Gloucester	Cheltenham 53471
DUNFORD & ELLIOTT (SHEFFIELD) LTD.	Attercliffe Wharf Works, Sheffield, 9	Sheffield 41121-4
DUNLOP RUBBER CO. LTD.	Fort Dunlop, Erdington, Birmingham, 24	Erdington 2121
ELECTRO-HYDRAULICS LTD.	Liverpool Road, Warrington	Warrington 2244
ENGLISH ELECTRIC CO. LTD.	Queens House, Kingsway, London, W.C.2	Holborn 6966
	Stafford	Stafford 700
FAIREY AVIATION CO. LTD.	Hayes, Middlesex	Hayes 3800
FIRTH, THOS. AND JOHN BROWN LTD.	Atlas and Norfolk Works, Sheffield, 1	Sheffield 20081, 26491
FIRTH-VICKERS STAINLESS STEELS LTD.	Staybrite Works, Sheffield	Sheffield 42051
FLIGHT REFUELLING LTD.	5 Clarges Street, London, W.1	Grosvenor 5741
	Tarrant Rushton Airfield, Blandford, Dorset	Blandford 501
FOLLAND AIRCRAFT LTD.	Hamble, Southampton, Hants.	Hamble 3191
GLOSTER AIRCRAFT CO. LTD.	Gloster Works and Aerodrome, Hucclecote, Glos.	Gloucester 66294
GRAVINER MANUFACTURING CO. LTD.	(Aircraft Division Sales Dept.), Poyle Mill Works, Colnbrook, Bucks.	Colnbrook 48-49
HANDLEY PAGE LTD.	Cricklewood, London, N.W.2	Gladstone 8000
HAWKER AIRCRAFT LTD.	Canbury Park Road, Kingston-on-Thames	Kingston 1044
HESTON AIRCRAFT CO. LTD., THE	Heston Airport, Middlesex	Southall 2321
HIGH DUTY ALLOYS LTD.	Slough, Bucks.	Slough 21201
HOBSON, H. M., LTD.	Hobson Works, Fordhouses, Wolverhampton	Fordhouses 2266
HUGHES, F. A., & CO. LTD.	Bath House, 82 Piccadilly, London, W.1	Grosvenor 6300
HUGHES, HENRY & SON, LTD.	Husun Works, New North Road, Barkingside, Essex	Hainault 2601
HUGHES-JOHNSON STAMPINGS LTD., THE	Langley Green, Birmingham	Broadwell 1361
HYMATIC ENGINEERING CO. LTD.	Redditch, Worcestershire	Redditch 743
ILIFFE AND SONS LTD.	Dorset House, Stamford Street, London, S.E.1	Waterloo 3333
IMPERIAL CHEMICAL INDUSTRIES LTD.	Nobel House, 2 Buckingham Gate, London, S.W.1.	Victoria 4444
IMPERIAL CHEMICAL INDUSTRIES LTD. (METALS DIVISION)	Kynoch Works, Witton, Birmingham, 6	Birchfield 4848
INTEGRAL LTD.	Cousins Street, Dudley Road, Wolverhampton	Wolverhampton 24984
IRVING AIR CHUTE OF GREAT BRITAIN LTD.	Ickneild Way, Letchworth, Herts.	Letchworth 888
K.L.G. SPARKING PLUGS LTD.	Putney Vale, London, S.W.15	Putney 2671
KELVIN, BOTTOMLEY & BAIRD LTD.	Kelvin Avenue, Hillingdon, Glasgow, S.W.2	Halfway 3331
	Kelvin Works, Basingstoke	Basingstoke 690
LIGHT-METAL FORGINGS LTD.	Oldbury, Birmingham	Broadwell 1152
LODGE PLUGS LTD.	Rugby	Rugby 2076
MANGANESE BRONZE & BRASS CO. LTD., THE	Handford Works, Ipswich	Ipswich 2127
	63 Grosvenor Street, London, W.1	Mayfair 3058
MARSTON EXCELSIOR LTD.	Wolverhampton	Fordhouses (W'ton) 2181
	49/59 Armley Road, Leeds, 12	Leeds 37351
		Armley 38081-5
MARTIN-BAKER AIRCRAFT CO. LTD.	Higher Denham, Bucks.	Denham 2214
MCMICHAEL RADIO LTD.	Slough, Bucks.	Slough 22311
	190 Strand London, W.C.2	Temple Bar 2085
MOLLART ENGINEERING CO. LTD.	Kingston By-Pass, Surbiton, Surrey	Elmbridge 3352-4
MOND NICKEL CO. LTD., THE	Sunderland House, Curzon Street, London, W.1	Grosvenor 4131

DIRECTORY OF ADVERTISERS

Napier D., & Son Ltd.	Acton, London, W.3	Shepherds Bush 1226
Palmer Tyre Ltd., The	Herga House, Vincent Square, London, S.W.1	Victoria 8323
Percival Aircraft Ltd.	Luton Airport, Luton, Beds.	Luton 2960
Peto & Radford	Chequers Lane, Dagenham, Essex	Rainham 34
Pitman, Sir Isaac & Sons Ltd.	Parker Street, Kingsway, London, W.C.2	Holborn 9791
Plessey Co. Ltd., The	Vicarage Lane, Ilford, Essex	Ilford 3040
Pullin, R. B., & Co. Ltd.	Phoenix Works, Great West Road, Brentford, Middx.	Ealing 0011-3, 3661-3
Pulsometer Engineering Co. Ltd., The	Nine Elms Iron Works, Reading.	Tilehurst 67182-4
	39 Victoria Street, London, S.W.1	Abbey 4565
Qantas Empire Airways	c/o British Overseas Airways Corporation, Airways Terminus, Buckingham Palace Road, S.W.1	Victoria 3126
Roe, A. V., & Co Ltd.	Greengate, Middleton, Manchester	Failsworth 2020-2039
Rolls-Royce Ltd.	Derby	Derby 2424
Rotax Ltd.	Willesden Junction, London, N.W.10	Elgar 7777
Rotol Ltd.	Cheltenham Road, Gloucester	Gloucester 24431
Sangamo Weston Ltd.	Great Cambridge Road, Enfield, Middlesex	Enfield 3434 & 1242
Saunders-Roe Ltd.	Head Office: Osborne, E. Cowes, Isle of Wight	Cowes 445
	London Office: 45 Parliament St., Westminster, S.W.1	Whitehall 7271
Serck Radiators Ltd.	Warwick Road, Birmingham, 11	Victoria 0531
Shell-Mex and B.P. Ltd.	Shell-Mex House, Strand, London, W.C.2	Temple Bar 1234
Short Brothers and Harland Ltd.	Seaplane Works, Queen's Island, Belfast	Belfast 58444
Skyhi Ltd.	"Skyhi" Works, Worton Road, Isleworth, Middlesex	Hounslow 2211
Smiths Aircraft Instruments Ltd.	Cricklewood Works, London, N.W.3	Gladstone 3333
Sozol (1924) Ltd.	2 Copthall Buildings, London, E.C.2	Monarch 6830
Sperry Gyroscope Co. Ltd., The	Great West Road, Brentford, Middlesex	Ealing 6771
Sterling Metals Ltd.	Northey, Foleshill, Coventry	Coventry 89031
Temple Press Ltd.	Bowling Green Lane, London, E.C.1	Terminus 3636
United Steel Companies Ltd., The	17 Westbourne Road, Sheffield, 10	Sheffield 60081
Vickers-Armstrongs Ltd.	Vickers House, Broadway, Westminster, S.W.1	Abbey 7777
	Weybridge Works, Weybridge, Surrey	Byfleet 240-243
	Supermarine Works, Hursley Park, Winchester, Hants.	Chandlersford 2251
Vokes Ltd.	Henley Park, near Guildford, Surrey	Guildford 62861
Wakefield, C. C., & Co. Ltd.	46 Grosvenor Street, London, W.1	Mayfair 9232
Wellworthy Piston Rings Ltd.	Radial Works, Lymington, Hants.	Lymington 520
Westland Aircraft Ltd.	Yeovil, Somerset	Yeovil 1100
Wickman, A. C., Ltd.	Tile Hill, Coventry	Tile Hill 66271
Wiggin, Henry, & Co. Ltd.	Wiggin Street, Birmingham	Edgbaston 2245
Yorkshire Engineering Supplies Ltd.	Bronze Foundries, Upper Wortley Road, Leeds, 12	Leeds 38234 & 38291

The Journal is published monthly at the Offices of the Society, 4 Hamilton Place, Piccadilly, London, W1. None of the papers or paragraphs must be taken as expressing the opinion of the Council of The Royal Aeronautical Society unless such is definitely stated to be the case. Subscriptions per annum, £4 13 0 including postage: Single Numbers 7/6 or 7/9 post free. All communications for publication or Advertisements in the Journal, or on general matters affecting the Society should be addressed to—The Secretary, J. Laurence Pritchard, 4 Hamilton Place, W1. The Society's Bankers are Messrs. Coutts & Co.

Telephone: Grosvenor 3515 (5 lines). Telegraphic Address: Didaskalos, Audley, London.

MAKING FLYING SAFER

No. 2 of a Series

Resetting Fire and Temperature Detector Switches

The first announcement in this series outlined the unique experience of the Graviner Organisation in the development of new and better methods of aircraft fire protection, with particular reference to flame and temperature detection problems. The practical application of this experience is seen in the Graviner Unit Resetting Detector, now in quantity production, which has been designed and approved for use in potential fire zones where normal operating ambient temperatures do not exceed 260 C.

Expansion of the barrel as a result of fire or sufficient rise in temperature removes the compressive force from the bow assembly and permits the contacts to close. On the temperature dropping, the barrel contracts thus compressing the bow assembly and re-opening the contacts. This proven principle of differential expansion enables the Graviner Company to offer the Industry a positive Resetting Fire Detector requiring no complicated accessories, so maintaining the simplicity in design essential to efficient operation.

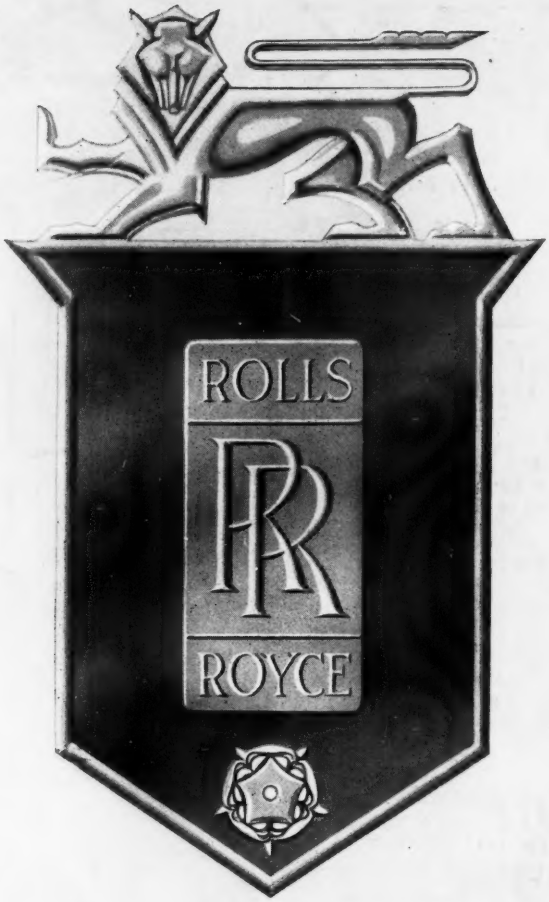
Illustrated brochure available on request to airline operators—aircraft constructors—chief designers and technical librarians

GRAVINER

Airborne **FIRE PROTECTION EQUIPMENT**

THE GRAVINER MANUFACTURING CO LTD, POYLE MILL WORKS
COLNBROOK, BUCKS *Telephone : Colnbrook 48*

Agents in Argentina, Australia, Canada, Denmark, East Africa, Holland, India and Pakistan, Italy, New Zealand, Sweden, U.S.A.



ROLLS-ROYCE

Aero

ENGINES

FOR SPEED AND RELIABILITY

ROLLS ROYCE LIMITED DERBY

Printed by the Lewes Press (Wightman & Co. Ltd.), Friars Walk, Lewes, England, and Published by The Royal Aeronautical Society, 4 Hamilton Place, London, W.1, England.